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CONTENTS

	Page
The water vapor in the atmosphere over the United States east of the Rocky Mountains. (28 figs.) Louis P. Harrison	449
Solar radiation as a meteorological factor. (13 figs.) Herbert H. Kimball	472
International meetings in September and October, 1931. Charles F. Brooks	480
Locarno meeting of the Meteorological Committee, October, 1931. Charles F. Marvin	481
White lightning versus red as a fire hazard. William J. Humphreys	481
Several cloud spouts. Edward M. Brooks	482
A tornado cloud in the free air. Alfred C. Hawkins	482
Preliminary statement of tornadoes in the United States during 1931. Herbert C. Hunter	483
The weather of 1931 in the United States. Herbert C. Hunter. (2 tables and 2 charts)	483
Bibliography	484
Solar Observations	485
Aerological Observations	486
Weather in the United States:	
The weather elements	488
Rivers and floods	490
Weather on the Atlantic and Pacific Oceans	491
Climatological Tables	496
Charts I–XL	

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ON THE WATER VAPOR IN THE ATMOSPHERE OVER THE UNITED STATES EAST OF THE ROCKY MOUNTAINS

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CONTENTS

	Page
I. Purpose of investigation	449
II. Theory of method	449
III. The empirical data	451
IV. Computation of constants of the equations	452
V. Discussion of formulas; causes of errors, etc.	460
VI. Comparative study of the data: Seasonal and geographical	467
VII. Summary	471

INTRODUCTION

I. PURPOSE OF INVESTIGATION

The purpose of this investigation is threefold:

1. To provide a practical method of computing the total mass of water vapor in the lower strata, i. e., to 3 or 4 kilometers, of the atmosphere based upon certain surface observations.

2. To deduce empirical equations based upon the mean values of available data for the lower strata for purposes of extrapolation to obtain tentative approximations of the mass of water vapor in the higher layers of the troposphere.

3. To ascertain and study the average distribution of water vapor in the lower strata of the atmosphere over the United States east of the Rocky Mountains.

II. THEORY OF METHOD

1. *General theory.*—From the gas laws, the mass of water vapor contained in a cubic meter of space is given by

$$1.060\ \frac{e_{mm.}}{1+\alpha t}=0.79507\ \frac{e_{mb.}}{1+\alpha t}=\text{absolute humidity, grams/cu. m.}$$

where e = vapor pressure in units indicated (mm. of mercury, or mb.).
t = temperature in °C.
α = thermal coefficient of cubical expansion, 0.00367.

If e_s = vapor pressure at the surface station, we may write for the absolute humidity at any height, h,

$$W_h=Ke_s\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}\ \text{grams per cubic meter} \tag{1}$$

or

$$W_h=Ke_sf_h\ \text{grams per cubic meter} \tag{1'}$$

where we define $f_h=\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}$, and where K has the value 1.060 when e_s is expressed in millimeters of mercury, and the value 0.79507 when e_s is expressed in millibars. The subscript h refers to the height at which the data are determined. The mass of water vapor in a layer of infinitesimal thickness dh and unit area is

$$dS=W_h\,dh\ \text{grams,} \tag{2}$$

whence S_a^b, the total mass of water vapor contained in a column of air 1 square meter in cross section and extending from $h=a$ to $h=b$ in meters above sea level, is

$$S_a^b=\int_{h=a}^{h=b}W_h\,dh \tag{3}$$

Substituting equation 1 in equation 3 we get,

$$S_a^b=Ke_s\int_{h=a}^{h=b}\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}dh \tag{4}$$

or

$$S_a^b=K\,e_s\,F_a^b\ \text{grams,} \tag{4'}$$

where by analogy we define $F_a^b=\int_a^b\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}dh$, the sub and super scripts referring to limits of integration.

From the empirical studies of Hann (1), Süring (2) and others, it has been shown that for average conditions the ratio $\left(\frac{e_h}{e_s}\right)$ is nearly constant for each height for widely differing geographical locations, and that it is independent of the value e_s. Hence we may express this value as a function of height,

$$\left(\frac{e_h}{e_s}\right)=\theta(h). \tag{5}$$

Likewise with suitable restrictions upon place and time, for average conditions, we may express t_h as a function of height,

$$t_h=\psi(h). \tag{6}$$

Hence it follows that with the proper restrictions, for average conditions, we find S to be a function of height, thus

$$S_a^b=K\,e_s\int_a^b\frac{\theta(h)}{1+\alpha\psi(h)}dh. \tag{7}$$

It is clear that to determine the mass of water vapor in the given column of air of unit cross-section, we may

either compute the value of the integral by numerical integration of equation *4*, making use of empirical data, or we may obtain the functions $\theta(h)$ and $\psi(h)$ and integrate formally as indicated in equation 7.

2. *Application to the lower strata.*—From what has been stated above, in the case of numerical integration of equation *4* where empirical data are available, for a given place and season we should find the value of the integral F°_{s} to be a constant for a given height of column $(b-a)$, under average conditions.

The evaluation of a sufficient number of such integrals for various places and seasons thus affords a simple means of computing the value S°_{a}, provided that simple corrections to the values of the integrals may be found for places at heights above sea level different from those of the base stations, and provided also that geographic interpolations of the integrals are permissible. Under these circumstances the value e_s is determined currently and the value S°_{a} thus computed is an approximation to the mass of water vapor in the given column of air. The actual value of this variable differs from the computed value depending upon the deviation of the current value of the integral F°_{s} from its average value. Other factors which may introduce errors will be discussed in a later section (V).

The practicability of employing the alternative method of finding the value of the integral (i. e., determining the required functional relationships) depends to a great extent upon the complexity of the relationships and their variability with time and place. As may be seen from the data presented in the following section, the actual relationships differ in many small details both with respect to geographic location and to season. For practical purposes it is not essential to be able to reproduce the empirical values

$$f_h=\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}$$

by means of an analytical function, if we have available empirical curves of this function plotted against height, or values of the areas under these curves for suitable limits. Therefore it has been decided to employ this method to determine the values of the integrals for the lower strata of the atmosphere where considerable observational data are available.

3. *Application to the higher strata.*—Thus far, at least three empirical equations have been deduced, giving the average value of the ratio $\left(\frac{e_h}{e_s}\right)$ as a function of height. The well-known equation of Hann (loc. cit.) based largely upon observations made at mountain stations gives

$$(8)\qquad \left(\frac{e_h}{e_o}\right)=10^{-\frac{h}{6300}},$$

where h is the height in meters above sea level at which e_h is the vapor pressure, and e_o is the vapor pressure at sea level.

The equation deduced by Süring (loc. cit.) for the free air is

$$(9)\qquad \left(\frac{e_h}{e_o}\right)=10^{-\left(\frac{h}{6}+\frac{h^2}{120}\right)},$$

where h is here expressed in kilometers.

Süring in the work previously mentioned, on testing the applicability of Hann's equation for values in the free air found that the use of one constant such as 6,500 gave values which were too great above 1 kilometer. However, by dividing up the height into several layers and using an appropriate constant for each layer, the data might be represented fairly closely by this equation. Thus it is stated in the Lehrbuch der Meteorologie of Hann and Süring (fourth edition, p. 244), that "For heights as high as 4.5 km., balloon observations show the constant to be 5,250 m. with good agreement; from 4.5 to 8 km. the constant is 3,550 m. on the average. (4,150 m. is found as the general average)."

On the basis of one year's observations at the Preussischen Aeronautischen Observatorium at Lindenberg, Hergesell (3) has found e_h as a function of temperature and therefrom, e_h as a function of height. He finds

$$(10)\qquad \left(\frac{e_h}{e_s}\right)=10^{10.231\left(\frac{t_h}{T_h}-\frac{t_s}{T_s}\right)}$$

where

t_h = temp. in °C. at height h.
t_s = temp. in °C. at the surface of the earth.
T_h = absolute temp. $(273+t)$ °K. at height h.
T_s = absolute temp. $(273+t)$ °K at surface.

Expressing $\left(\frac{t}{T}\right)$ as a function of height he finds for Lindenberg.

$$(11)\qquad e_h=7.046\times10^{-\left(\frac{h}{8}+\frac{h^2}{48}\right)}\text{ mm. of mercury,}$$

where h = height above sea level in kilometers. Equation 10 showed good agreement with the means of observations at Batavia, except for values near the height 1.75 km. It was noted in this work that the data would have been fit more closely by the use of a third-order polynomial instead of one of the second order as shown.

Since the value $(1+\alpha t_h)$ does not differ very greatly from unity for temperatures in the troposphere, it is to be expected from the foregoing that only a first approximation to the function $f_h=\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}$ is to be obtained by the use of an exponential function of the type given by Hann, and that closer approximation is obtained by the use of a higher polynomial in the expression. In this connection is may be noted that the evidence at hand shows quite conclusively that in general a Hann type equation gives values which are much too high at heights above 5 km. Thus in one set of data tried, such an equation gave values of the function at 10 km. equivalent to 200 per cent relative humidity.

Data based on a number of sounding balloon flights made in the United States showed for the interval 4–7 km. that the average variation of the function f_h with height could be represented fairly well by means of a second-order exponential function. A greater interval was not used since the hair hygrometer readings for greater heights were increasingly doubtful due to lag in the hygrometer elements (**4**).

Extrapolation of the function f_h in question by means of a second-order exponential expression is found to give reasonable values for high levels in the great majority of cases. The integration of the resulting function provides a means of obtaining the approximate mass of water

vapor in the higher strata for which relatively few or no reliable observations are available.

III. THE EMPIRICAL DATA

The data used were obtained from the mean seasonal values of free-air vapor pressures and temperatures, for the stations shown in Table 1. In general, one observation was attempted each day.

TABLE 1.—*Sources of observations*

Station	Altitude, m. s. l.	Latitude N.		Longitude W.		Period of observations (inclusive)				Length of record	
						From—		To—			
	m.	°	′	°	′					*Yrs.*	*Mos.*
Broken Arrow, Okla.	233	36	02	95	49	August,	1918	February,	1929	10	7
Drexel, Nebr.	396	41	20	96	16	November,	1915	March,	1926	10	5
Due West, S. C.	217	34	21	82	22	March,	1921	February,	1929	8	0
Ellendale, N. Dak.	444	45	59	98	34	January,	1918	February,	1929	11	2
Groesbeck, Tex.	141	31	30	96	28	October,	1918	February,	1929	10	5
Leesburg, Ga.	85	31	47	84	14	March,	1919	June,	1920	1	4
Naval Air Station, Washington, D. C.	7	38	54	77	03	July,	1925	February,	1929	3	8
Royal Center, Ind.	225	40	53	86	29	July,	1918	February,	1929	10	8

All of these stations with the exception of the naval air station at Washington, D. C., made the observations by means of kites and captive balloons. The latter station employed airplanes. Observations at the kite stations were usually begun between 7 and 8 a. m., local standard time, and generally lasted from 2 to 3½ hours. More or less variation in the time of beginning an observation was practised. In some cases launching of kites occurred before 7 a. m., and in others as late as 10 a. m. A small proportion of the flights were made during the afternoon. Airplane observations at Washington, D. C., during the period covered by the data showed no great regularity with regard to time of beginning. The flights in this case usually were started between 8 and 9 a. m., and lasted from 15 to 30 minutes. The data may thus be considered as representative of early to midmorning conditions.

The values of the function

$$\left\{\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}\right\}$$

given in Table 2 were computed from corresponding seasonal means of vapor pressure and temperature, respectively. The seasonal means were computed from monthly means, each month's means being given equal weight. Each season was considered to be of three months duration, as follows:

Spring	March. April. May.	Autumn	September. October. November.
Summer	June. July. August.	Winter	December. January. February.

The method of differences was used in computing all means, i. e., the arithmetic mean of the surface values is first obtained, then the mean differences from level to level of daily or monthly observed values are computed and finally added successively to the surface mean to give the means for the various levels.

Table 2, which follows, also indicates the total number of daily observations upon which the computed values of the function are based. The seasonal mean *surface* vapor pressures and temperatures are tabulated in the first two columns.

TABLE 2.—*Seasonal values of the function* $f_h=\left\{\frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}\right\}$

BROKEN ARROW, OKLA. (Surface altitude 233 m., m. s. l.)

Season	Surface: Mean vapor pressure	Surface: Mean temperature	Designation (1)	Surface	250	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000
	Mb.	*°C.*																			
Spring	12.09	15.0	*a*	0.9478	0.9395	0.8339	0.7518	0.6877	0.6181	0.5498	0.4332	0.3437	0.2783	0.2296	0.1841	0.1479	*0.1300	0.1085	......	......	......
			b	778	778	778	774	768	740	695	586	455	330	192	90	40	14	6	......	......	......
Summer	23.21	26.1	*a*	0.9126	0.9050	0.8099	0.7324	0.6686	0.6077	0.5488	0.4421	0.3502	0.2808	0.2251	0.1786	0.1401	0.1121	*0.1082	0.1029	0.1002	......
			b	686	686	686	684	676	639	597	501	405	279	161	70	33	8	3	2	1	......
Autumn	13.60	16.6	*a*	0.9426	0.9360	0.8456	0.7689	0.7069	0.6445	0.5781	0.4476	0.3434	0.2664	0.2106	0.1536	0.1186	*0.0987	0.0010	......	......	......
			b	762	762	762	760	744	725	662	560	454	315	192	91	37	8	2	......	......	......
Winter	6.06	4.1	*a*	0.9852	0.9772	0.8738	0.7853	0.7105	0.6374	0.5729	0.4623	0.3848	0.3247	0.2771	0.2357	0.1934	0.1641	0.1392	*0.0962	......	......
			b	775	773	772	766	749	706	644	530	411	276	156	91	39	14	6	1	......	......

DREXEL, NEBR. (Surface altitude 396 m., m. s. l.)

Season	Surface: Mean vapor pressure	Surface: Mean temperature	Designation (1)	Surface	250	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000
Spring	8.22	9.3	*a*	0.9670	......	0.9190	0.8183	0.7439	0.6747	0.6099	0.4976	0.4120	0.3424	0.2802	0.2279	0.1873	0.1444	*0.1069	0.0819	0.0642	......
			b	903	......	903	901	876	845	801	693	547	415	242	110	42	20	10	6	2	......
Summer	18.87	22.9	*a*	0.9225	......	0.8724	0.7712	0.7023	0.6414	0.5807	0.4748	0.3848	0.3110	0.2506	0.1992	0.1653	0.1347	*0.1218	0.1134	......	......
			b	811	......	811	807	778	752	716	605	498	380	246	122	42	15	6	4	......	......
Autumn	9.52	11.1	*a*	0.9609	......	0.9211	0.8333	0.7630	0.6995	0.6396	0.5336	0.4443	0.3660	0.2977	0.2473	0.2054	0.1662	0.1349	*0.1025	0.0867	......
			b	867	......	867	863	849	828	793	700	589	473	330	171	72	24	13	5	2	......
Winter	3.66	−4.6	*a*	1.0172	......	0.9702	0.8885	0.8389	0.7959	0.7463	0.6417	0.5461	0.4609	0.3769	0.3002	0.2448	0.2067	*0.1826	......	......	......
			b	939	......	938	925	900	880	846	760	656	494	278	115	34	14	4	......	......	......

TABLE 2.—*Seasonal values of the function* $f_h = \left\{ \dfrac{\left(\dfrac{e_h}{e_s}\right)}{1+\alpha t_h} \right\}$—Continued

Season	Surface: Mean vapor pressure	Surface: Mean temperature	Designation	Altitude above sea level, meters: Surface	250	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000
DUE WEST, S. C. (Surface altitude 217 m., m. s. l.)																					
	Mb.	*°C.*																			
Spring	12.13	16.4	a	0.9432	0.9286	0.8312	0.7591	0.7000	0.6422	0.5798	0.4561	0.3493	0.2655	0.2042	0.1636	0.1341	*0.1169				
			b	524	524	524	512	481	438	403	334	253	166	104	51	16	9				
Summer	22.30	26.3	a	0.9120	0.8997	0.8119	0.7464	0.6907	0.6353	0.5780	0.4731	0.3863	0.3135	0.2592	0.2102	0.1788	*0.1122	0.0632			
			b	387	387	386	371	332	292	251	199	163	116	69	32	19	3	1			
Autumn	13.81	17.0	a	0.9413	0.9272	0.8402	0.7721	0.7174	0.6570	0.5969	0.4735	0.3769	0.3109	0.2621	0.2232	0.2021	*0.1773	0.1670			
			b	465	465	465	452	408	372	327	266	203	131	75	33	15	6	2			
Winter	7.74	7.3	a	0.9739	0.9617	0.8763	0.8196	0.7644	0.7041	0.6390	0.5189	0.4080	0.3229	0.2561	0.2112	*0.1625	0.1386				
			b	523	523	521	510	482	439	401	336	248	158	69	30	10	4				
ELLENDALE, N. DAK. (Surface altitude 444 m., m. s. l.)																					
Spring	6.29	5.6	a	0.9798		0.9545	0.8446	0.7675	0.7039	0.6434	0.5308	0.4311	0.3443	0.2738	0.2135	0.1635	0.1279	*0.0952	0.0789	0.0655	0.0537
			b	949		948	945	931	901	851	730	580	415	252	130	56	20	6	3	2	1
Summer	15.85	20.0	a	0.9316		0.9049	0.7979	0.7216	0.6549	0.5903	0.4799	0.3957	0.3209	0.2631	0.2174	0.1802	0.1524	*0.1423	0.1326		
			b	910		910	910	900	861	811	680	548	403	266	148	64	13	4	2		
Autumn	7.51	6.4	a	0.9770		0.9579	0.8749	0.7995	0.7254	0.6578	0.5466	0.4571	0.3810	0.3101	0.2529	0.2043	0.1544	0.1224	0.1001	*0.0691	0.0640
			b	928		928	925	917	890	847	738	590	444	294	152	59	26	17	4	2	1
Winter	2.56	−10.1	a	1.0385		1.0178	0.9581	0.9219	0.8876	0.8354	0.7145	0.5984	0.4769	0.3656	0.2897	0.2461	0.1890	0.1435	*0.1354		
			b	949		947	945	929	888	843	728	584	395	216	95	32	9	5	1		
GROESBECK, TEX. (Surface altitude 141 m., m. s. l.)																					
Spring	15.43	17.9	a	0.9384	0.9010	0.8144	0.7375	0.6545	0.5683	0.4842	0.3589	0.2833	0.2328	0.1922	0.1619	0.1380	*0.1341	0.1206			
			b	833	832	830	816	785	743	693	581	442	282	138	68	26	14	4			
Summer	25.19	26.4	a	0.9117	0.8836	0.8082	0.7136	0.6206	0.5507	0.4923	0.3967	0.3238	0.2662	0.2191	0.1807	0.1463	*0.1311				
			b	755	755	753	728	695	652	598	454	318	176	84	38	12	6				
Autumn	17.21	18.8	a	0.9355	0.9032	0.8261	0.7533	0.6744	0.5989	0.5330	0.4099	0.3160	0.2416	0.1928	0.1503	0.1215	0.1013	0.0767			
			b	761	761	756	732	696	643	592	494	396	278	154	84	35	13	4			
Winter	9.26	9.0	a	0.9681	0.9290	0.8478	0.7772	0.6953	0.6228	0.5495	0.4300	0.3491	0.2842	0.2304	0.1964	0.1651	0.1424	0.1225	*0.1127	0.1068	0.1031
			b	844	844	840	808	762	708	650	552	426	299	163	79	43	21	6	1	1	1
LEESBURG, GA. (Surface altitude 85 m., m. s. l.)																					
Spring	14.98	20.0	a	0.9316	0.8611	0.7830	0.7214	0.6659	0.6100	0.5494	0.4066	0.3479	0.2820	*0.2549	0.2337	0.2200					
			b	88	88	84	77	65	59	49	32	25	20	10	4	3					
Summer	24.86	28.6	a	0.9050	0.8451	0.7830	0.7418	0.6855	0.6207	0.5526	0.4472	0.3677	0.3274	0.2848	*0.2598						
			b	51	51	51	45	37	29	27	24	19	15	7	3						
Autumn	18.40	23.5	a	0.9206	0.8702	0.8077	0.7453	0.6780	0.6177	0.5468	0.4065	0.2982	0.2282	0.1791	*0.1591	0.1298					
			b	48	48	47	43	36	32	29	22	18	14	9	6	3					
Winter	10.00	12.7	a	0.9555	0.8920	0.8102	0.7508	0.6856	0.6223	0.5612	0.4319	0.3541	0.2922	*0.2112	0.1545	0.1440					
			b	67	67	66	60	56	53	48	44	37	25	10	4	2					
NAVAL AIR STATION, WASHINGTON, D. C. (surface altitude 7 m., m. s. l.)																					
Spring	9.77	12.1	a	0.9575	0.8680	0.7752	0.6943	0.6376	0.5902	0.5495	0.4550	0.3632	0.2847	0.2322	0.1746	*0.1210	0.0790	0.0502	0.0286		
			b	175	176	175	174	171	168	162	146	120	89	61	45	7	2	1	1		
Summer	21.70	24.2	a	0.9184	0.8382	0.7491	0.6758	0.6143	0.5615	0.5195	0.4370	0.3448	0.2616	0.2001	0.1463	*0.0705	0.0374	0.0114			
			b	175	175	175	171	169	165	161	144	127	106	38	30	2	1	1			
Autumn	13.49	14.6	a	0.9491	0.8659	0.7909	0.7259	0.6738	0.6230	0.5706	0.4599	0.3553	0.2636	0.1936	*0.1325	0.0849	0.0420				
			b	185	185	183	183	181	175	169	151	129	91	35	17	1	1				
Winter	4.87	1.3	a	0.9953	0.9260	0.8523	0.7968	0.7393	0.6853	0.6327	0.5390	0.4545	0.3655	0.2944	*0.2459	0.2155					
			b	149	149	146	146	144	142	139	124	103	60	19	12	2					
ROYAL CENTER, IND. (surface altitude 225 m., m. s. l.)																					
Spring	8.84	10.2	a	0.9639	0.9492	0.8269	0.7437	0.6754	0.6111	0.5541	0.4536	0.3520	0.2775	0.2236	0.1814	0.1537	*0.1364	0.1273	0.1120		
			b	704	704	704	693	665	633	597	486	359	242	136	73	39	18	7	1		
Summer	18.69	23.4	a	0.9209	0.9090	0.8071	0.7415	0.6862	0.6271	0.5631	0.4382	0.3258	0.2479	0.1875	0.1456	*0.1238	0.1101	0.1051	0.0871		
			b	588	584	583	564	529	491	460	388	286	182	104	44	16	4	3	1		
Autumn	11.20	12.7	a	0.9555	0.9450	0.8479	0.7757	0.7043	0.6341	0.5669	0.4485	0.3529	0.2826	0.2265	0.1640	0.1345	*0.1109	0.0858			
			b	722	720	719	701	662	618	583	485	392	274	138	54	24	7	2			
Winter	4.32	−2.5	a	1.0093	0.9937	0.8834	0.8070	0.7321	0.6595	0.5992	0.4929	0.4200	0.3611	0.3016	0.2505	0.2162	0.1759				
			b	773	773	773	752	729	680	634	528	370	208	96	31	7	1				

[1] a = value of function f_h, b = number of observations.

* Values thus indicated and those for higher levels considered relatively doubtful.

Values of the function are computed to four decimal places; however, they are not to be regarded as accurate to that many figures, except possibly where based upon a large number of observations. In general, values based upon fewer than about 25 observations are considered to be in doubt in the second and possibly in the first decimal place. (See Secs. IV and V for discussions of errors.)

IV. COMPUTATION OF CONSTANTS OF THE EQUATIONS

1. Graphical integration of equation (4) for given data.—The function f_h has been plotted against height for the data given in TABLE 2. Some examples of the resulting curves are shown in Figures 1–8, for Ellendale, N. Dak., and Groesbeck, Tex., the most northern and southern stations, respectively, in the given group.

The evaluation of equation 4 was accomplished by drawing smooth curves through the plotted points as shown in the above figures, and reading the mean values of the ordinates f_h for each hundred-meter interval. The value of the definite integral is then obtained when the sum of the resulting mean ordinates is multiplied by 100. This method has advantages over the usual meth-

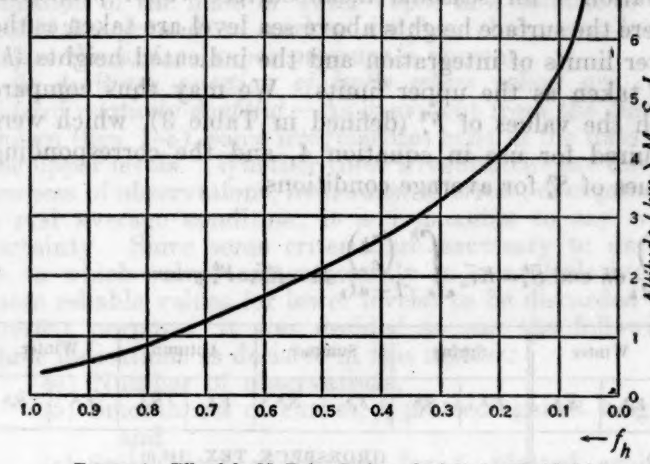

FIGURE 1.—Ellendale, N. Dak. Spring. f_h plotted against height

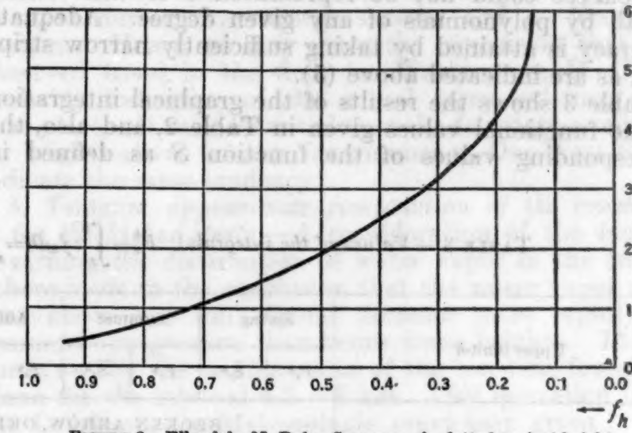

FIGURE 2.—Ellendale, N. Dak. Summer. f_h plotted against height

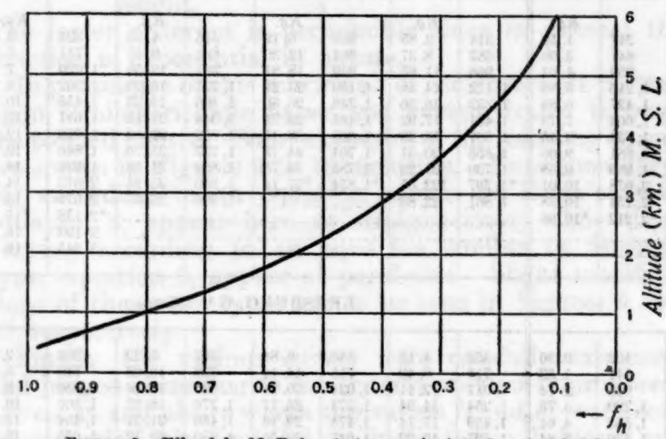

FIGURE 3.—Ellendale, N. Dak. Autumn. f_h plotted against height

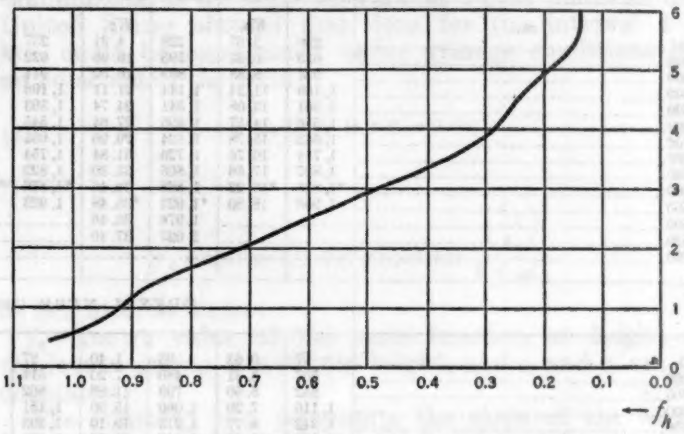

FIGURE 4.—Ellendale, N. Dak. Winter. f_h plotted against height

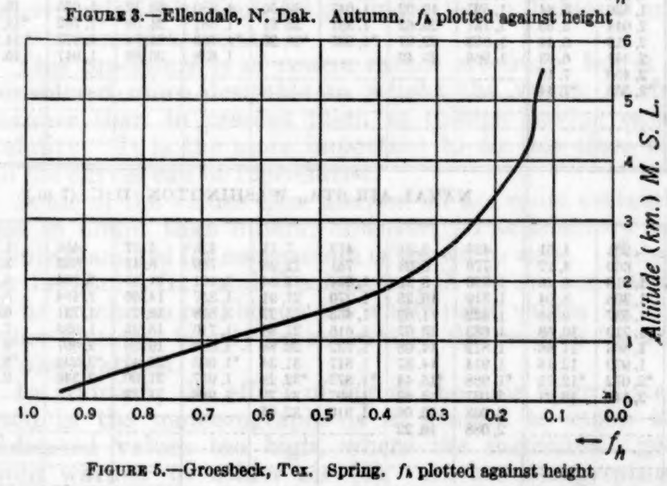

FIGURE 5.—Groesbeck, Tex. Spring. f_h plotted against height

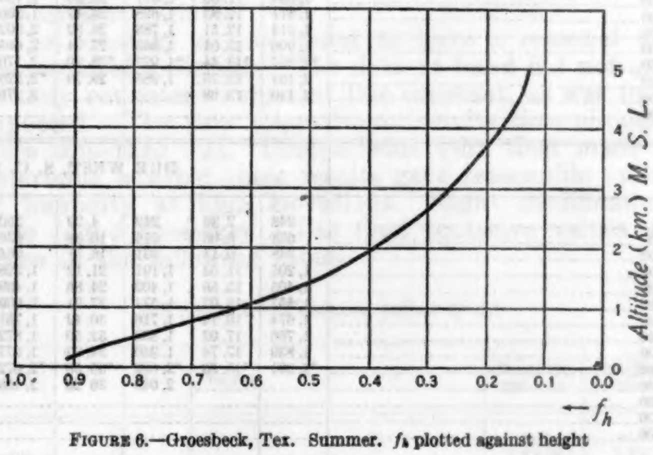

FIGURE 6.—Groesbeck, Tex. Summer. f_h plotted against height

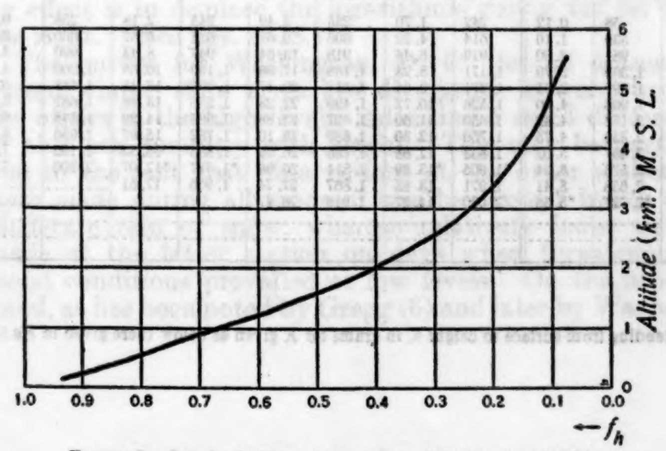

FIGURE 7.—Groesbeck, Tex. Autumn. f_h plotted against height

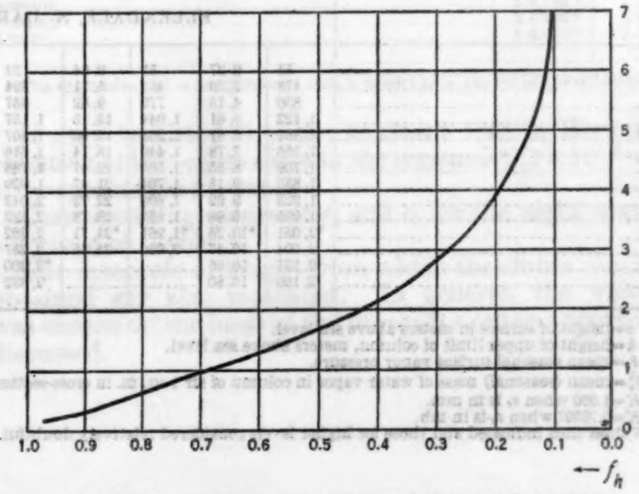

FIGURE 8.—Groesbeck, Tex. Winter. f_h plotted against height

ods of numerical integration such as Simpson's rules, since the curves could not be represented over their entire length by polynomials of any given degree. Adequate accuracy is attained by taking sufficiently narrow strips such as are indicated above (**5**).

Table 3 shows the results of the graphical integration of the functional values given in Table 2, and also, the corresponding values of the function S as defined in equation 4 for seasonal mean surface vapor pressures, where the surface heights above sea level are taken as the lower limits of integration and the indicated heights (h) are taken as the upper limits. We may thus compare both the values of F_s^h (defined in Table 3), which were required for use in equation 4, and the corresponding values of S_s^h for average conditions.

TABLE 3.—*Values of the integrals*[1]: $F_s^h=\int_s^h f_h dh=\int_s^h \frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}dh$ *and* $\bar{S}_s^h=K\bar{e}_s\int_s^h \frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}dh=K\bar{e}_s\cdot F_s^h$ *grams*

Upper limit-h	Spring F_s^h	Spring $\bar{S}_s^h$	Summer F_s^h	Summer $\bar{S}_s^h$	Autumn F_s^h	Autumn $\bar{S}_s^h$	Winter F_s^h	Winter $\bar{S}_s^h$	Spring F_s^h	Spring $\bar{S}_s^h$	Summer F_s^h	Summer $\bar{S}_s^h$	Autumn F_s^h	Autumn $\bar{S}_s^h$	Winter F_s^h	Winter $\bar{S}_s^h$
	BROKEN ARROW, OKLA. (233 m.)								GROESBECK, TEX. (141 m.)							
m.		Kg.		Kg.		Kg.		Kg.		Kg.		Kg.		Kg.		Kg.
500	236	2.27	228	4.21	237	2.56	247	1.19	314	3.85	309	6.19	316	4.32	324	2.39
1,000	615	5.91	595	10.98	622	6.72	641	3.09	682	8.37	664	13.30	691	9.45	711	5.23
1,500	924	8.88	899	16.59	944	10.20	959	4.62	966	11.85	939	18.81	991	13.56	1,020	7.51
2,000	1,169	11.24	1,144	21.11	1,196	12.93	1,216	5.86	1,172	14.38	1,159	23.21	1,225	16.76	1,262	9.29
2,500	1,361	13.08	1,341	24.74	1,393	15.06	1,427	6.88	1,333	16.36	1,338	26.80	1,406	19.23	1,455	10.71
3,000	1,516	14.57	1,498	27.64	1,545	16.70	1,604	7.73	1,461	17.93	1,485	29.74	1,544	21.12	1,611	11.86
3,500	1,642	15.78	1,624	29.96	1,664	17.99	1,754	8.45	1,567	19.23	1,605	32.15	1,652	22.60	1,739	12.80
4,000	1,744	16.76	1,726	31.84	1,754	18.96	1,881	9.06	1,655	20.31	1,704	34.13	1,737	23.76	1,846	13.59
4,500	1,827	17.56	1,805	33.30	1,822	19.70	1,989	9.58	1,730	21.23	1,785	35.75	1,804	24.68	1,936	14.25
5,000	*1,896	*18.22	1,868	34.46	*1,876	*20.28	2,078	10.01	*1,797	*22.05	*1,854	*37.14	1,860	25.44	2,013	14.82
5,500	1,956	18.80	*1,923	*35.48	1,923	20.79	2,154	10.38	1,861	22.83			1,906	26.07	2,079	15.31
6,000			1,976	36.46			*2,212	*10.66							*2,138	*15.74
6,500			2,027	37.40											2,193	16.14
7,000															2,245	16.53
	DREXEL, NEBR. (396 m.)								LEESBURG, GA. (85 m.)							
500	97	0.63	93	1.40	97	0.73	102	0.30	352	4.19	346	6.84	357	5.22	366	2.91
1,000	507	3.31	480	7.20	514	3.89	547	1.59	713	8.49	715	14.14	728	10.65	740	5.88
1,500	842	5.50	799	11.98	862	6.52	943	2.74	1,017	12.11	1,024	20.24	1,036	15.16	1,050	8.35
2,000	1,116	7.29	1,060	15.90	1,151	8.71	1,290	3.75	1,254	14.94	1,273	25.17	1,276	18.67	1,300	10.34
2,500	1,342	8.77	1,273	19.10	1,393	10.54	1,585	4.61	1,439	17.14	1,475	29.16	1,450	21.21	1,494	11.88
3,000	1,530	10.00	1,447	21.70	1,593	12.06	1,836	5.34	1,597	19.02	1,647	32.56	1,580	23.12	1,655	13.16
3,500	1,684	11.00	1,587	23.80	1,756	13.29	2,044	5.95	*1,731	*20.62	1,801	35.61	1,681	24.59	*1,782	*14.17
4,000	1,811	11.83	1,698	25.47	1,890	14.31	2,213	6.44	1,853	22.07	*1,935	*38.25	*1,766	*25.84	1,873	14.89
4,500	1,914	12.51	1,788	26.82	2,002	15.15	2,347	6.83	1,966	23.42			1,838	26.89	1,947	15.48
5,000	1,996	13.04	1,863	27.94	2,095	15.86	2,459	7.16								
5,500	*2,057	*13.44	*1,927	*28.90	2,170	16.42	*2,555	*7.44								
6,000	2,104	13.75	1,985	29.78	*2,228	*16.86										
6,500	2,140	13.98			2,276	17.23										
7,000																
	DUE WEST, S. C. (217 m.)								NAVAL AIR STA., WASHINGTON, D. C. (7 m.)							
500	248	2.39	242	4.29	250	2.74	261	1.61	426	3.31	412	7.11	426	4.57	456	1.77
1,000	628	6.06	614	10.89	636	6.98	669	4.12	776	6.03	751	12.95	789	8.47	853	3.30
1,500	948	9.14	931	16.51	965	10.60	1,018	6.26	1,070	8.31	1,034	17.84	1,101	11.81	1,194	4.62
2,000	1,205	11.62	1,191	21.12	1,228	13.48	1,306	8.04	1,319	10.25	1,270	21.91	1,357	14.56	1,484	5.75
2,500	1,405	13.55	1,402	24.86	1,439	15.80	1,537	9.46	1,522	11.82	1,465	25.27	1,558	16.72	1,731	6.70
3,000	1,557	15.02	1,574	27.91	1,609	17.67	1,719	10.58	1,683	13.07	1,616	27.88	1,710	18.35	1,935	7.49
3,500	1,674	16.14	1,716	30.42	1,751	19.23	1,863	11.46	1,812	14.08	1,732	29.88	1,823	19.56	2,097	8.12
4,000	1,766	17.03	1,833	32.50	1,872	20.55	1,979	12.18	1,914	14.87	1,817	31.34	*1,903	*20.42	*2,232	*8.64
4,500	1,839	17.74	1,930	34.22	1,977	21.71	*2,072	*12.75	*1,988	*15.44	*1,872	*32.29	1,957	21.00	2,346	9.08
5,000	*1,901	*18.33	*2,002	*35.50	*2,072	*22.75	2,146	13.21	2,037	15.82	1,897	32.72	1,988	21.33		
5,500			2,045	36.26	2,158	23.60			2,068	16.06	1,910	32.95				
6,000									2,088	16.22						
6,500																
7,000																
	ELLENDALE, N. DAK. (444 m.)								ROYAL CENTER, IND. (225 m.)							
500	54	0.27	51	0.64	54	0.32	58	0.12	242	1.70	235	3.49	245	2.18	258	0.89
1,000	478	2.39	453	5.71	494	2.95	539	1.10	614	4.32	606	9.01	631	5.62	660	2.27
1,500	830	4.15	779	9.82	857	5.12	981	2.00	919	6.46	918	13.64	947	8.43	990	3.40
2,000	1,122	5.61	1,044	13.15	1,157	6.91	1,369	2.79	1,171	8.23	1,168	17.36	1,190	10.68	1,260	4.33
2,500	1,361	6.81	1,262	15.90	1,407	8.40	1,697	3.45	1,371	9.64	1,357	20.17	1,398	12.45	1,488	5.11
3,000	1,555	7.78	1,440	18.14	1,616	9.65	1,966	4.00	1,526	10.72	1,499	22.28	1,556	13.86	1,682	5.78
3,500	1,709	8.55	1,585	19.97	1,788	10.68	2,174	4.42	1,650	11.60	1,607	23.88	1,683	14.99	1,848	6.35
4,000	1,830	9.15	1,704	21.47	1,929	11.52	2,334	4.75	1,750	12.30	1,689	25.10	1,782	15.87	1,986	6.82
4,500	1,923	9.62	1,804	22.73	2,042	12.19	2,467	5.02	1,833	12.88	*1,756	*26.09	1,855	16.52	2,102	7.22
5,000	1,995	9.98	1,887	23.78	2,132	12.73	2,576	5.24	*1,905	*13.39	1,814	26.96	*1,917	*17.07	2,200	7.56
5,500	*2,051	*10.26	*1,961	*24.71	2,202	13.15	2,658	5.41	1,971	13.85	1,867	27.74	1,966	17.51		
6,000	2,094	10.47	2,030	25.58	2,257	13.48	*2,727	*5.55	2,030	14.27	1,916	28.47				
6,500	2,131	10.66			*2,300	*13.73										
7,000	2,160	10.80			2,332	13.92										

[1] s=height of surface in meters above sea-level.
h=height of upper limit of column, meters above sea level.
$\bar{e}_s$=mean seasonal surface vapor pressure.
$\bar{S}_s^h$=mean (seasonal) mass of water vapor in column of air 1 sq. m. in cross-section and extending from surface to height h, in grams for K given as below (here given in $Kg.$).
K=1.060 when e_s is in mm.
K=0.79507 when e_s is in mb.
*Values thus indicated and those for higher levels considered relatively doubtful.

The values of F_s^h introduced above permit the computation of the mass of water vapor in a column of air from the ground to various heights above sea level, where the surface vapor pressure is known.

2. *Arbitrary selection of levels where values are considered relatively doubtful.*—As is evident from the curves shown (figs. 1–8), some irregularities exist in the data for the upper levels. Whether these irregularities are due to fewness of observations, instrumental errors, or represent a real average condition, it is impossible to say with certainty. Since some criteria are necessary to decide as to which values are sufficiently in error (relative to more reliable values for lower levels) to be discarded for present purposes, it was decided to use the following three indications as decisive in this matter:

(*a*) Number of observations,
(*b*) Smoothness of curves, f_h plotted against height, and
(*c*) Smoothness of curves, log f_h plotted against height.

The latter criterion is permissible since in general the function is exponential in nature.

In pursuance of this scheme all of the data were plotted upon semilogarithmic paper and curves drawn through the plotted points. Some examples of the resulting curves are shown in Figures 9 to 18 inclusive. Functions varying according to an equation similar to Hann's type, equation 8, appear here as straight lines, while those varying according to an equation similar to Süring's type, equation 9, appear as parabolas. Slight modifications of these two types are to be seen in Figures 9 and 10, respectively.

Finally the various curves were carefully examined and judged according to the criteria previously proposed. Levels at and above which the values f_h and F_s^h were considered relatively doubtful are indicated in Tables 2 and 3 by means of asterisks.

This procedure is of course rather arbitrary, but it is considered more desirable to weight the values in this manner than to present them as though having equal validity. It is the more important to do this since not all the curves can be reproduced.

Some of the values thus marked off are quite certainly less in doubt than others; however, no satisfactory absolute standard for comparison is known to exist. Values for Leesburg, Ga., and Washington, D. C., are considered to be much less reliable on the whole than values for the other stations, largely on account of the relative fewness of observations.

In addition, the effect of lag in the hair hygrometers used in the meteorographs is in general to make the indicated values too high, where the instrument goes from warmer to colder air (**4**). At low temperatures (below $-30°$ C.) this effect has been found by Kleinschimdt (loc. cit.) to be quite large. The result of such an effect is to displace the logarithmic curves too far to the right. (See figs. 9–18.)

The curves for Washington, D. C., for all seasons, except winter, show a marked divergence in trend from the others in the high levels, indicating a rapid decrease of absolute humidity with height. This may be partly due to the fact that observations at the other stations were made during all kinds of weather except heavy or moderate rain or snow, whereas relatively fewer were made at the latter station on days when threatening, moist conditions prevailed at low levels. On the other hand, as has been noted by Gregg (**6**) and later by Wagner (**7**), temperatures in the free air are lower over the Atlantic coast than at corresponding latitudes in the interior of the continent. This is most strongly pronounced during the warmer seasons and at Northern stations. Hence we may draw the conclusion that the observed trend in the data for Washington, D. C., is probably indicative of the actual trend existing over that place. It may be noted that the few data available for heights above 4.5 km., for summer at Due West, S. C., indicate the same tendency.

3. *Tentative approximate computation of the constants* ***F*** *for the higher strata.*—A consideration of the factors governing the distribution of water vapor in the troposphere leads to the conclusion that the water vapor content above 4–5 km. should decrease more rapidly in geometric progression than below those heights. This is borne out by the smaller value of the constant found by Hann for the interval 4.5 – 8 km. (See quotation from the Lehrbuch der Meteorologie previously given.) An examination of 91 sounding-balloon flights made in the United States showed that data for the interval 4–7 km. could be represented under average conditions by an equation of the form

$$f_h = f_d 10^{-[c_1(h-d)+c_2(h-d)^2]} \tag{12}$$

where

$$f_h = \text{value of the function } \frac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}$$

at height h, in meters.

f_d = known value of the same function at height d, the latter serving as a datum height, and c_1 and c_2 are constants.

The constant $-c_1$ represents the slope of the semilogarithmic curve at height d, h being taken as the independent variable.

The constant c_2 was found to have a seasonal and geographical variation. The data at hand did not give entirely consistent values of this constant, as was to be expected. The very approximate results thus obtained were smoothed out. Comparisons were then made to determine whether these results gave reasonable values of humidity at high elevations. Slight modifications were found necessary. The final tentative values are given in the following table:

TABLE 4.—*Tentative values of c_2**

Season	Northern stations	Southern stations
	m.$^{-2}$	*m.*$^{-2}$
Spring	2.6×10^{-8}	2.5×10^{-8}
Summer	2.0×10^{-8}	1.9×10^{-8}
Autumn	2.4×10^{-8}	2.1×10^{-8}
Winter	3.0×10^{-8}	2.7×10^{-8}

* The dimensions of c_2 are reciprocal square meters as indicated at the column heads

It may be noted that the constant 1/48 in Hergesell's equation (11) is equivalent to the constant 2.1×10^{-8} when h is expressed in meters.

Corresponding values of f_d and c_1 for the eight stations are given in Table 5.

The intervals of height from which the slopes $-c_1$ were obtained are also indicated. In general, the value f_d was chosen on the basis of the reliability criteria previously discussed.

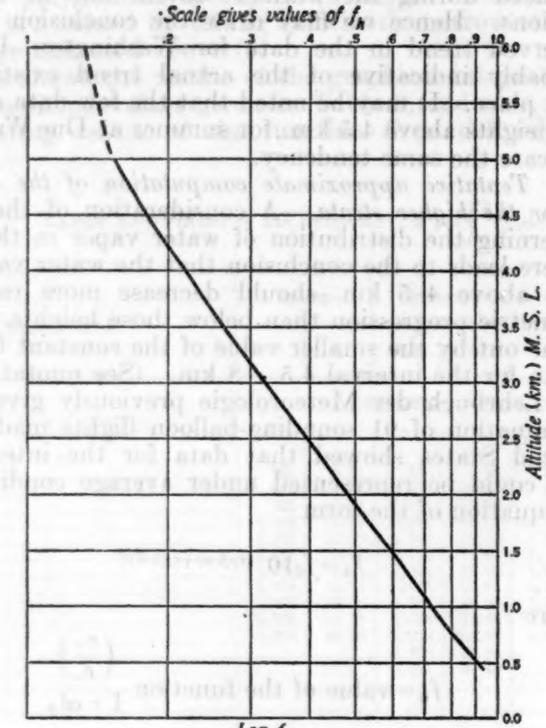

FIGURE 9.—Ellendale, N. Dak. Summer. $\text{Log}_{10} f_h$ plotted against height

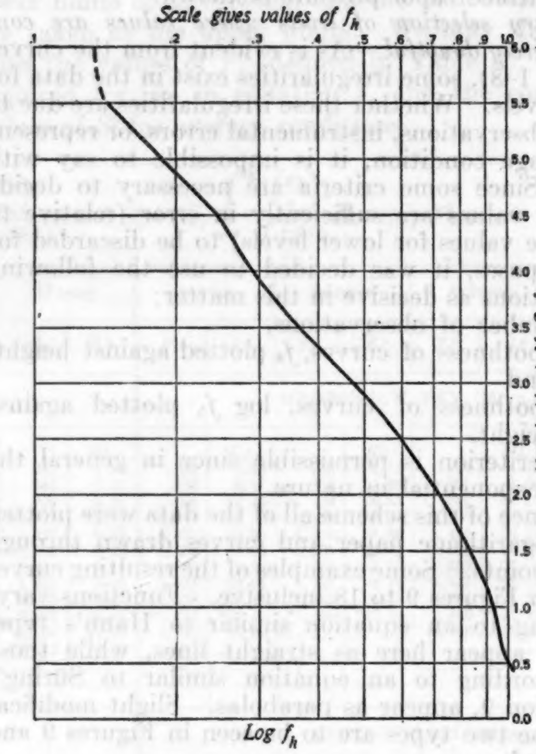

FIGURE 10.—Ellendale, N. Dak. Winter. $\text{Log}_{10} f_h$ plotted against height

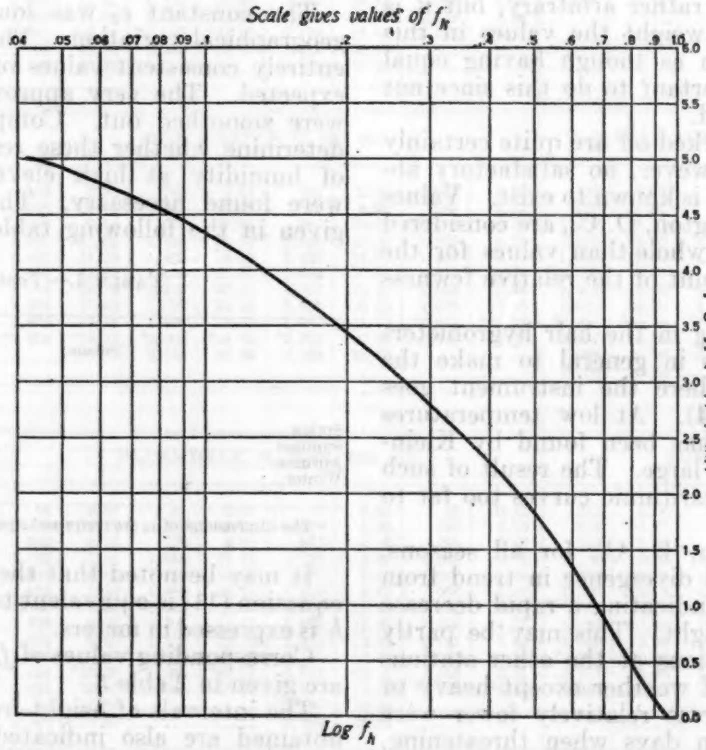

FIGURE 11.—Washington, D. C. Autumn. $\text{Log}_{10} f_h$ plotted against height

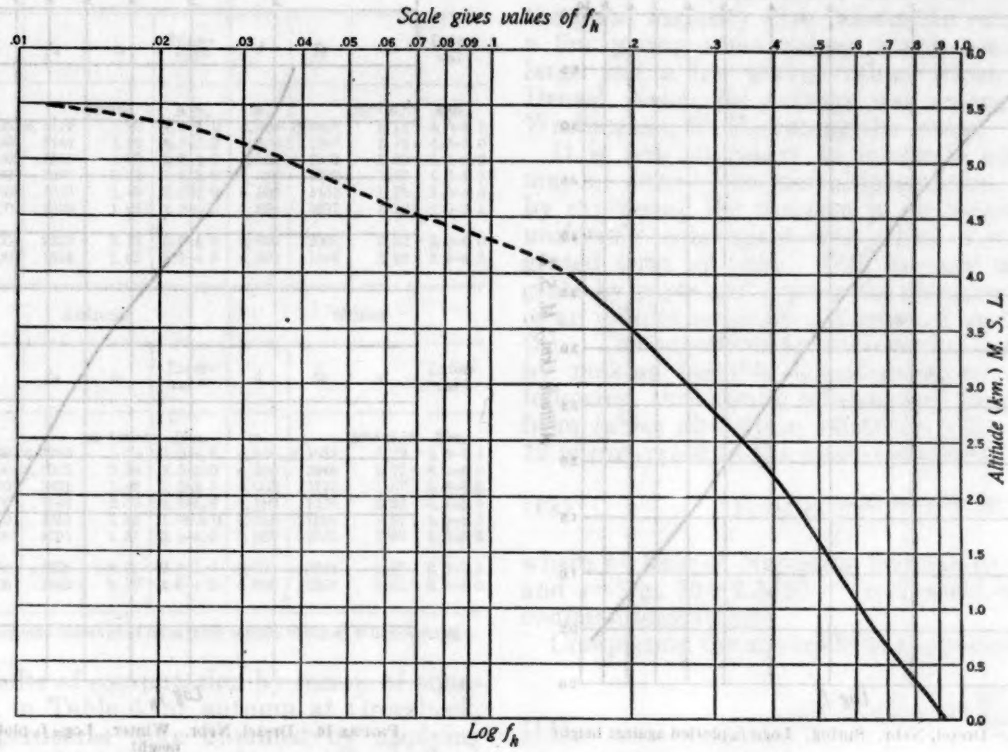

FIGURE 12.—Washington, D. C. Summer. $\log_{10} f_h$ plotted against height

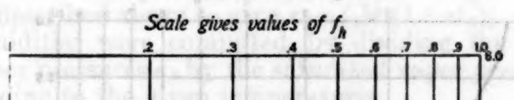

FIGURE 13.—Washington, D. C. Winter. $\log_{10} f_h$ plotted against height

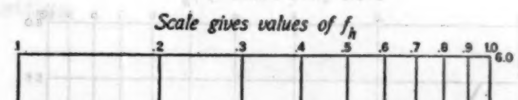

FIGURE 14.—Royal Center, Ind. Summer. $\log_{10} f_h$ plotted against height

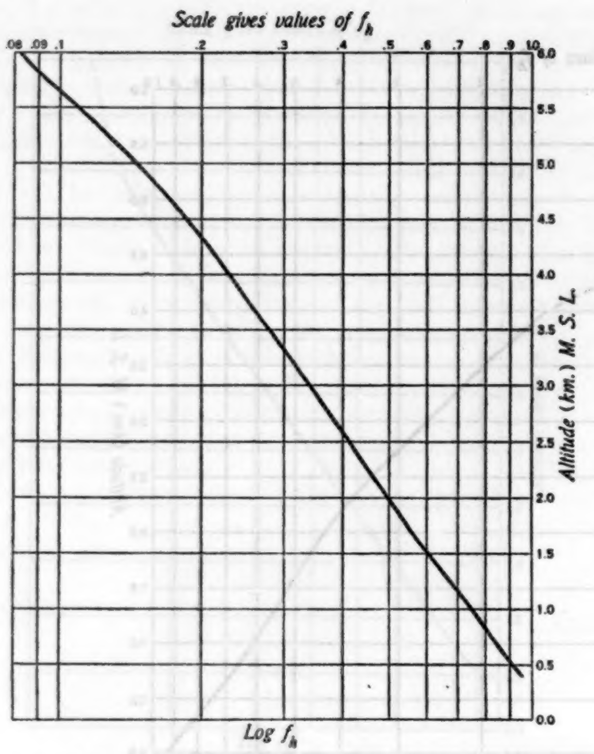

FIGURE 15.—Drexel, Nebr. Spring. $\log_{10} f_h$ plotted against height

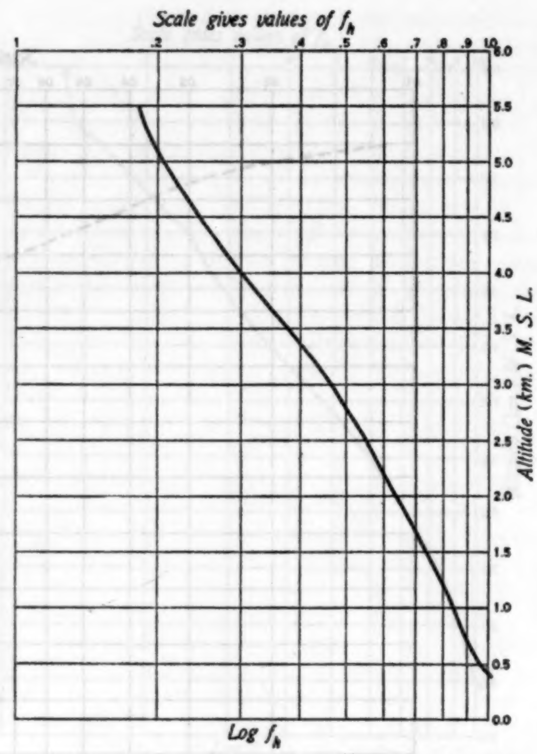

FIGURE 16.—Drexel, Nebr. Winter. $\log_{10} f_h$ plotted against height

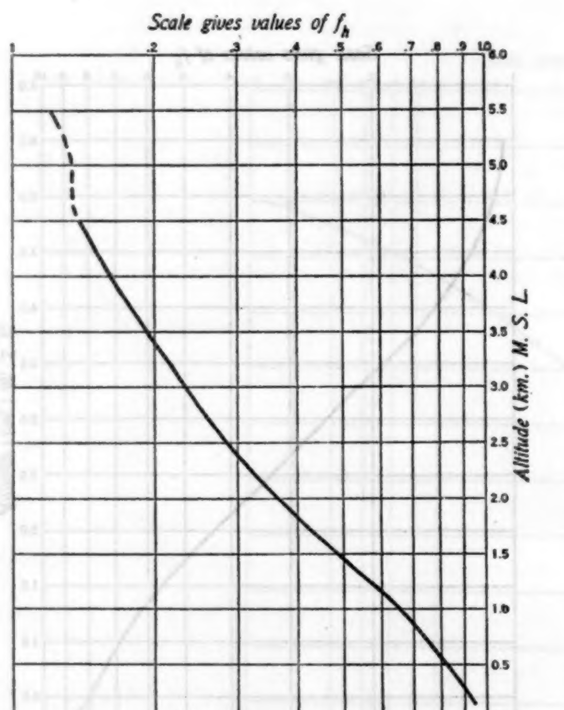

FIGURE 17.—Groesbeck, Tex. Spring. $\log_{10} f_h$ plotted against height

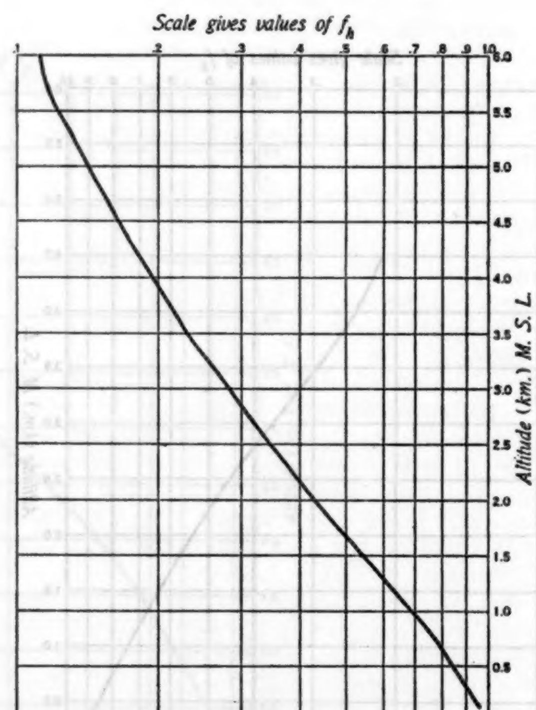

FIGURE 18.—Groesbeck, Tex. Winter. $\log_{10} f_h$ plotted against height

TABLE 5.—*Data used for extrapolation of f_h to heights greater than for which it is available, according to equation 12*

Station	Spring				Summer			
	d	f_d	c_1	Interval [1]	d	f_d	c_1	Interval [1]
	m.		$10^{-4}m.^{-1}$	*Km.*	*m.*		$10^{-4}m.^{-1}$	*Km.*
Broken Arrow, Okla	4,500	0.1479	1.90	4.0–4.5	4,500	0.1401	2.11	4.0–4.5
Drexel, Nebr	5,000	.1444	2.26	4.5–5.0	5,000	.1347	1.78	4.5–5.0
Due West, S. C	4,000	.1636	1.93	3.5–4.0	4,000	.2102	1.82	3.5–4.0
Ellendale, N. Dak	5,000	.1279	2.13	4.5–5.0	4,500	.1802	1.63	4.0–4.5
Groesbeck, Tex	4,000	.1619	1.49	3.5–4.0	4,500	.1463	1.75	3.5–4.5
Leesburg, Ga	3,000	.2820	1.82	2.5–3.0	2,500	.3677	1.70	2.0–2.5
Naval Air Station, Washington, D. C	3,500	.2322	2.12	3.0–4.0	3,500	.2001	2.52	3.0–4.0
Royal Center, Ind	4,000	.1814	1.82	3.5–4.0	4,000	.1456	1.80	3.5–4.5

Station	Autumn				Winter			
	d	f_d	c_1	Interval [1]	d	f_d	c_1	Interval [1]
	m.		$10^{-4}m.^{-1}$	*Km.*	*m.*		$10^{-4}m.^{-1}$	*Km.*
Broken Arrow, Okla	4,500	0.1186	2.25	4.0–4.5	4,500	0.1934	1.72	4.0–4.5
Drexel, Nebr	6,000	.1025	2.39	5.5–6.0	4,500	.2448	1.77	4.0–4.5
Due West, S. C	3,500	.2621	1.48	3.0–3.5	4,000	.2112	1.67	3.5–4.0
Ellendale, N. Dak	5,000	.1544	2.22	4.5–5.0	5,500	.1435	2.34	4.5–5.5
Groesbeck, Tex	4,500	.1215	1.85	4.0–5.0	4,500	.1651	1.51	4.0–4.5
Leesburg, Ga	3,500	.1791	1.57	3.0–4.0	3,000	.2922	1.67	2.5–3.0
Naval Air Station, Washington, D. C	3,000	.2636	2.59	2.5–3.0	3,500	.2944	1.88	3.0–3.5
Royal Center, Ind	4,500	.1345	1.72	4.0–4.5	4,000	.2505	1.61	3.5–4.0

[1] Columns thus headed indicate interval of data from which value c_1 was obtained.

Examples of results of computation by means of equation 12 are shown in Table 6 for autumn at Groesbeck, Tex. Mean temperatures were obtained by applying the mean lapse rates obtained from the sounding-balloon series of October, 1927, made at that station (8) to the mean temperature at 4 km., which had been obtained from kite records for the season in question. Vapor pressures were computed by using the temperatures found as described above to give $e_h = f_h[\bar{e}_s(1+at_h)]$. Relative humidities were computed by dividing the computed vapor pressures e_h by the saturated vapor pressures corresponding to the given temperatures.

TABLE 6.—*Examples of use of equation 12*

Groesbeck, Tex.—Autumn season				
h	t	f_h	e_h	Relative humidity
COMPUTED VALUES				
Km.	*°C.*		*mb.*	%
4.5	−1.4	0.1215	2.08	38
5.0	−4.3	.0971	1.64	38
5.5	−7.6	.0756	1.26	39
6.0	−11.0	.0575	.949	40
7.0	−18.3	.0310	.498	41
8.0	−26.2	.0152	.236	42
9.0	−33.7	.00671	.101	39
10.0	−40.5	.00270	.0396	33
11.0	−46.4	.000988	.0141	24
12.0	−51.4	.000328	.00458	14
13.0	−55.7	.0000988	.00135	7
14.0	−59.8	.0000270	.000363	3
15.0	−63.6	.0000067	.000069	1
OBSERVED VALUES (KITES)				
4.5	−1.3	0.1215	2.08	[1] 37
5.0	−3.8	.1013	1.72	35
5.5	−6.2	.0767	1.29	31

[1] Based on 35, 13, and 4 observations, respectively. Latter appears too low.

It is to be noted that computation makes the relative humidity a maximum near 8 km., which is the region of maximum average lapse rates found in the troposphere.

Similar comparisons for the other stations show that the great majority give reasonable values of humidities, a few giving some values which seem somewhat too large and a few giving values which seem too small. Drexel, Nebr., for autumn was among the former, and Washington, D. C., among the latter.

It is now necessary to integrate equation 12. This may be done by numerical integration, or more formally by expressing the function in an infinite series which is uniformly convergent and which hence may be integrated term by term. Still another method is to integrate by parts and express the resulting integral in terms of an infinite series by a process of continued integration (9). These methods are necessarily laborious. However, by making suitable transformations as shown in the following, the definite integral may be quickly computed from tables already in existence. To do this, equation 12 is converted to the more convenient exponential form

$$f_h = f_d e^{-[c_2\kappa(h-d)^2 + c_1\kappa(h-d)]} \tag{13}$$

where e = base of Napierian logarithms

and $\kappa = \log_e 10 = 2.3026-$ = reciprocal of the modulus of common logarithms.

Completing the square in the exponent we get

$$f_h = f_d e^{\frac{c_1^2\kappa}{4c_2}} e^{-\left[\sqrt{c_2\kappa}\,(h-d) + \frac{c_1\sqrt{\kappa}}{2\sqrt{c_2}}\right]^2} \tag{14}$$

This reduces to

$$f_h = f_d 10^{\frac{c_1^2}{4c_2}} e^{-[\sqrt{c_2\kappa}]^2\left[h+\left(\frac{c_1}{2c_2}-d\right)\right]^2} \tag{15}$$

Letting

$$N = f_d 10^{\frac{c_1^2}{4c_2}}$$

$$a = \sqrt{c_2\kappa}$$

$$b = \left(\frac{c_1}{2c_2} - d\right),$$

the last equation simplifies to the form

$$f_h = N e^{-a^2[h+b]^2} \tag{16}$$

The desired integral is

$$\int_d^H f_h\,dh = N\int_d^H e^{-a^2[h+b]^2}\,dh \tag{17}$$

where H is the upper limit of integration.

From the geometry of the respective curves it becomes evident that

$$N\int_0^{h_1} e^{-a^2(h+b)^2}\,dh = N\int_0^{h_1+b} e^{-a^2h^2}\,dh - N\int_0^{b} e^{-a^2h^2}\,dh \tag{18}$$

where h_1 is any upper limit of integration. But since obviously

$$N\int_d^H e^{-a^2(h+b)^2}\,dh = N\int_0^H e^{-a^2(h+b)^2}\,dh - N\int_0^d e^{-a^2(h+b)^2}\,dh, \tag{19}$$

on substituting equation 18 into the right-hand members of equation 19, respectively, we get

$$(20)\qquad N\int_d^H e^{-a^2(h+b)^2}\,dh = N\int_0^{H+b} e^{-a^2h^2}\,dh - N\int_0^{d+b} e^{-a^2h^2}\,dh.$$

Let $t=ah$
then $dt=a\,dh$
and $dh=\frac{dt}{a}$, whence we have

$$(21)\qquad N\int_0^h e^{-a^2h^2}dh = \frac{N}{a}\int_0^{ah=t} e^{-t^2}dt.$$

Substituting equation 21 in equation 20 we obtain

$$(22)\qquad N\int_d^H e^{-a^2(h+b)^2}dh = \frac{N}{a}\int_0^{a(H+b)} e^{-t^2}dt - \frac{N}{a}\int_0^{a(d+b)} e^{-t^2}dt.$$

There are numerous tables available of the definite integral (**10**):

$$\theta(t) = \frac{2}{\sqrt{\pi}}\int_0^t e^{-t^2}dt$$

much used in the Theory of Probability. To adapt equation 22 for the use of such tables we rewrite it in the form

$$(23)\qquad N\int_d^H e^{-a^2(h+b)^2}dh = \left(\frac{\sqrt{\pi}}{2a}\right)N\left\{\frac{2}{\sqrt{\pi}}\int_0^{a(H+b)} e^{-t^2}dt - \frac{2}{\sqrt{\pi}}\int_0^{a(d+b)} e^{-t^2}dt\right\}$$

Noting that $a(d+b)=a\left(\frac{c_1}{2c_2}\right)$, we have finally for the special case where $H=\infty$ and $a\neq 0$, that

$$(24)\qquad F_d^\infty = N\int_d^\infty e^{-a^2(h+b)^2}dh = \left(\frac{\sqrt{\pi}}{2a}\right)N\left\{1-\frac{2}{\sqrt{\pi}}\int_0^{a\left(\frac{c_1}{2c_2}\right)} e^{-t^2}dt\right\}$$

where

$N=f_d 10^{\frac{c_1^2}{4c_2}}$
$a=\sqrt{c_2\kappa}$
$\kappa=2.3026-$, the other values as shown in Tables 4 and 5.

Table 7 (column F_d^∞) shows the results of integration for the higher strata, according to equation 24. Taking the upper limit as infinity introduces no significant error. The corresponding integrals for the lower strata are also given as well as the sums of the two respective integrals.

TABLE 7.—*Values of the factors F applying from the surface to the limits of the atmosphere*

Station	Spring				Summer			
	d	F_s^d	F_d^∞	[1] F_s^∞	d	F_s^d	F_d^∞	[1] F_s^∞
	Km.				*Km.*			
Broken Arrow, Okla	4.5	1,827	247	2,074	4.5	1,805	229	2,034
Drexel, Nebr	5.0	1,996	215	2,211	5.0	1,863	245	2,108
Due West, S. C	4.0	1,766	271	2,037	4.0	1,833	380	2,213
Ellendale, N. Dak	5.0	1,995	198	2,193	4.5	1,804	346	2,150
Groesbeck, Tex	4.0	1,655	311	1,966	4.5	1,785	272	2,057
Leesburg, Ga	3.0	1,597	485	2,082	2.5	1,475	694	2,169
Naval Air Station, Washington, D. C	3.5	1,812	363	2,175	3.5	1,732	289	2,021
Royal Center, Ind	4.0	1,750	309	2,059	4.0	1,689	263	1,952

Station	Autumn				Winter			
	d	F_s^d	F_d^∞	[1] F_s^∞	d	F_s^d	F_d^∞	[1] F_s^∞
	Km.				*Km.*			
Broken Arrow, Okla	4.5	1,822	183	2,005	4.5	1,989	338	2,327
Drexel, Nebr	6.0	2,228	149	2,377	4.5	2,347	411	2,758
Due West, S. C	3.5	1,751	526	2,277	4.0	1,979	375	2,354
Ellendale, N. Dak	5.0	2,132	236	2,368	5.5	2,658	204	2,862
Groesbeck, Tex	4.5	1,804	213	2,017	4.5	1,936	309	2,245
Leesburg, Ga	3.5	1,681	348	2,029	3.0	1,655	519	2,174
Naval Air Station, Washington, D. C	3.0	1,710	369	2,079	3.5	2,097	488	2,585
Royal Center, Ind	4.5	1,855	241	2,096	4.0	1,986	443	2,429

[1] See equation 4″ following, and text immediately thereafter.

We may note that F_s^∞ according to its definition by equation 4′, or

$$(4'')\qquad S_s^\infty = K\,e_s\,F_s^\infty \text{ grams,}$$

provides a means of computing approximately the mass of precipitable water vapor in a column one square meter in cross section and extending from the ground to the limits of the atmosphere. The function F_h^∞ is independent of the units in which the surface vapor pressure, e_s, is expressed. The value K, however, for our purposes, depends only upon the units in question. For convenience, we note here that

$K=1.060$ when e_s is in mm. mercury.
$K=0.79507$ when e_s is in mb.
$K=26.92$ when e_s is in inches of mercury.

It may be reiterated that the term F_d^∞ is only tentative. More reliable results can only be obtained by means of direct spectroscopic observations (**11**) to determine the desired values, or at least in part by means of reliable aerological observations, particularly of humidity, to great heights.

To obtain the desired value S_x^h for a station at height x differing from the height of the nearest of the 8 stations given herein, the surface vapor pressure e_x may be reduced to the corresponding vapor pressure at the surface of the "datum station," e_s, by the use of Hann's equation for mountain stations, thus

$$(8')\qquad e_s = e_x\,10^{\frac{(x-s)}{6300}}$$

In addition, the factor F_s^h obtained from Table 3 or 7 must be reduced by the amount F_s^x obtained from Table 3. Consequently, the final corrected value is

$$(25)\qquad S_x^h = K\,e_x 10^{\frac{(x-s)}{6300}}\,(F_s^h - F_s^x) \text{ grams.}$$

V. DISCUSSION OF FORMULAS; SOURCES OF ERRORS

1. *Comparisons with other formulas.*—Hann (**12**) has found that by changing the constant of his equation, 8, to make it conform more closely to conditions in the free air (i. e. changing from 6300 to 5000) and neglecting the temperature factor $(1+\alpha\, t_h)$, he gets what is equivalent to the expression,

$$(26)\qquad S_o^\infty = K\,e_o\,(2170) \text{ grams.}$$

The value in parenthesis compares closely with the average of the corresponding factors given in Table 7. Humphreys (**13**) has found from 74 balloon observations made in Europe that the yearly average for *clear* days is closely representable by what is equivalent to the expression

$$(27)\qquad S^\infty = K\,e_s\,(1930) \text{ grams,}$$

approximately, where h_s averaged between 200 and 300 meters. Here the agreement is reasonably close with the values for the warmer seasons—i. e., seasons with minimum cloudiness.

Fowle's spectro-bolometric observations on Mount Wilson (**11**) showed the mean value of F to be approximately half way between Hann's and Humphreys' values, or $F_o^\infty = 2040$ nearly, using Hann's equations for reduction to sea level. This value is based on observations made

during the months June–September, inclusive, 1910 and 1911.

2. *Sources of error in the formulas and results.*—As may readily be seen from the foregoing, the original assumptions that the ratio $\left(\frac{e_h}{e_s}\right)$ and t, or f_h, are explicit functions of height reduce to the proposition that the amount of water vapor over any small area of earth's surface is directly proportional to the vapor pressure at the surface. This is equivalent to saying that F_s^∞ is a constant independent of factors other than the height s. This is of course untrue, for obviously the value in question varies with time and with changing meteorological conditions in the atmosphere.

Where the time limit is sufficiently extended, the relationships may be expected to hold quite closely provided that unusual meteorological deviations from the average have not occurred. The relationship is also valid at times when a close approximation to the statistical "average condition" prevails.

(*a*) *Checking of normal exchange.*—The apparent constancy of the ratio $\left(\frac{e_h}{e_s}\right)$ found under the circumstances described has its foundation in the combined operations of convection, and mixing and diffusion of water vapor in the lower atmosphere. When little convection and mixing are occurring from the ground upward as may be the case where a strong inversion exists not far above ground, the average law of variation of this ratio with height may be departed from considerably. The ground may thus heat up, causing increased evaporation and thus increased vapor pressure, while almost no exchange is taking place between the ground layer and the layers above the inversion. The conditions above the inversion may consequently be largely tempered by the winds at those levels and regions from which the winds are blowing.

The relation which obtains between aqueous vapor at two levels in a convecting mass of air in which condensation and mixing has not yet taken place may be expressed simply by the equation

$$\frac{e_2}{p_2}=\frac{e_1}{p_1} \tag{28}$$

where e_1, p_1 are the vapor pressure and barometric pressure respectively at the original level, and e_2, p_2 are the corresponding values at a subsequent level. As an example of the average distribution of vapor pressure in the lower layers of the troposphere, we may cite the empirical equations found for average values during the spring season at Drexel, Nebr.,

$$\frac{e_h}{p_h}=\frac{e_s}{p_s}\,10^{-c_3(h-s)} \tag{29}$$

which applies from the surface $h\equiv s=396$ m. to $h=750$ m. (above sea level) and,

$$\frac{e_h}{p_h}=\frac{e_d}{p_d}\,10^{-c_4(h-d)} \tag{30}$$

which applies from $h\equiv d=750$ m. to $h=3500$ m., c_3 and c_4 being constants.

From the data at hand we find

$c_3=1.625\times10^{-4}$ (for h in meters)

$c_4=1.231\times10^{-4}$ (where $d=750$ m.)

and $\frac{p_d}{p_s}=0.958$.

These relationships show that, statistically, convection, turbulence and diffusion with the resultant mixing and condensation cause the ratios $\left(\frac{e}{p}\right)$ not to remain constant with height but to decrease in geometric ratio with increasing height.

It may be noted that in this case since $c_3>c_4$, the ratio in question decreases more rapidly from the ground (396 m.) to the height 750 m. above sea level than it does from 750 m. to 3,500 m. The effect of temperature lapse rates may now be seen from the values given in Table 8 following.

TABLE 8.—*Mean spring lapse rates, Drexel, Nebr.*

Interval	$-\frac{\Delta t}{\Delta h}$, °C./100m.	Interval	$-\frac{\Delta t}{\Delta h}$, °C./100m.
m.		*m.*	
396–500	0.67	1,500–2,000	0.44
500–750	.60	2,000–2,500	.52
750–1,000	.40	2,500–3,000	.56
1,000–1,250	.36	3,000–3,500	.58
1,250–1,500	.36	3,500–4,000	.58

It is evident from these values that convection is here relatively stronger in the first 350 m. above ground than above that height. The small lapse rates from 750–2,000 m. are due statistically to the inversions prevalent over northern stations during winter and early spring (**14**). Thus, as the generally moist ground warms up in spring, convection and turbulence raise considerable water vapor from the layers adjacent thereto, carrying it up to the region of small or inverted lapse rates where the convection is checked. From there the water vapor, tends to slowly diffuse upward, aided somewhat by the higher (gradient) wind velocities occurring at those levels, but since lapse rates in these layers are below adiabatic, eddy diffusion carries a portion of the water vapor back toward the ground layers. In addition, since the ground is comparatively moist in this season due to the after effects of the winter frost and snow cover, evaporation proceeds very rapidly near the ground especially during clear days, often adding water vapor to the ground layers more quickly than it can be carried aloft. This explains why the ratio $\left(\frac{e}{p}\right)$ decreases more slowly in the layer from 750–2,000 m., than it does immediately below it.

The concept under consideration is perhaps further verified by comparing the variation of these ratios with height for winter and summer at Ellendale, N. Dak.

Figure 19 shows plots of $\left[h, \log_{10}\frac{e}{p}\right]$ for the two seasons in question. The Summer curve is perhaps typical of average conditions when the stirring processes of the atmosphere have full play. The Winter curve shows the influence of the inversion in the lower layers. The mean seasonal lapse rates are shown by the small figures adjacent to each interval of height. The inversions in question are largely the result of the frequent "anticyclonic weather with its clear skies and intense radiation" (**6**) observed in these regions. The strong cooling of the lower layers due to radiation after sunset produces a subsidence of the air which thus becomes dynamically warmed. The continued cooling of the ground finally causes the temperature of the air at that level to become lower than that of the free air immediately above. The water vapor brought down by the subsidence of air thus finds itself in a region of diminished lapse rate and finally in an inversion. Convection is effectively checked under

such circumstances and the relative proportions of the constituent gases of the atmosphere tend to become fixed in amount. The evaporation of liquid or solid water falling through the inversion provides an important source of water vapor for the inversion layer when precipitation occurs. The water vapor, being less dense than dry air tends to diffuse molecularly toward the top of the inversion. Eddy diffusion, however, under the influence of increased wind velocities in the inversion layer plays an opposing rôle in the mechanism of the process, aiding in the general mixing of this constituent largely in the downward direction. The facts just adduced explain in part why the curve for winter is nearly vertical from the ground to about 1,000 m. elevation above.

Since molecular diffusion in the absence of convection and turbulence is relatively slow as an agency for dissi-

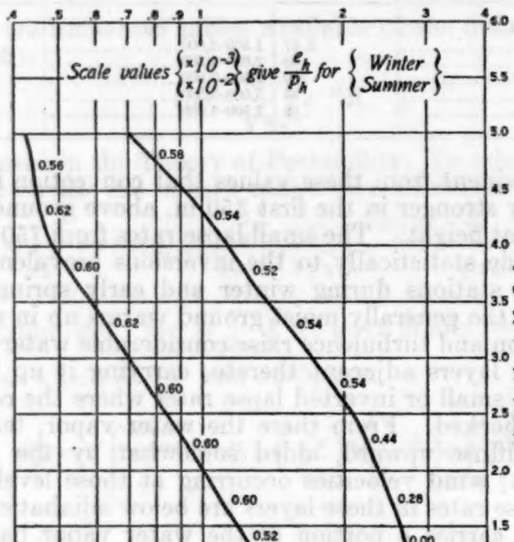

FIGURE 19.—Ellendale, N. Dak. Summer and winter. $\text{Log}_{10} \left(\frac{e}{p}\right)$ plotted against height. Small figures adjacent to curves are mean lapse rates for interval in °C./100 m. The winter values are less in absolute magnitude than the summer values. Winter surface value, $\left(\frac{e_s}{p_s}\right)=0.00275$; summer surface value, $\left(\frac{e_s}{p_s}\right)=0.0170$

pating water vapor, under the conditions outlined above, changes in the surface vapor pressure, say, due to surface heating at sunrise, are bound to take some time in making themselves felt at higher levels. It may also be noted that the higher temperatures in the inversion increase the capacity of the space for water vapor so that relatively large amounts of vapor may be present without condensing.

Thus, cases of abnormally large factors F_w observed by Fowle at Mount Wilson (11), height 1,730 m., may be due to the forced convection of a stratum of air over the mountain, the air being of oceanic origin and having a strong inversion and low humidity at the height in question. Such conditions are very common in the Summer on the California coast (15). Thus with near normal moisture content in the free air above but low vapor pressure at the mountain top and an inversion just above it to prevent normal convection, the factor in question would become abnormally large.

(*b*) *Diurnal variation in relative distribution of water vapor with height.*—As is well known the diurnal march of vapor pressure at the surface generally shows a regular periodic variation. Inland regions in summer show two maxima and two minima, occurring at about 6 to 9 a. m. and 8 to 9 p. m., for the former, and 3 to 4 p. m. and 3 to 4 a. m., for the latter (12[b]). In general, the oceans in summer and winter and most inland regions in winter show but one maximum and one minimum, similar to the diurnal march of temperature, the maximum occurring during the afternoon and the minimum during the early morning. Coastal stations show variations between the extremes outlined above, but resemble the oceans most closely.

The causes of this diurnal march of absolute humidity at the surface are substantially as follows. In *summer*, at *inland* stations, the ground at dawn is greatly cooled due to the nocturnal radiation, especially so if the night has been clear. The subsidence of the air during the night due to this cooling and to the relative absence of convection carries much moisture down to the ground layers from the atmosphere. These two processes conduce to the process of condensation near the ground, and the formation of dew, especially if vegetation is present. Hence the low temperatures near the ground cause the space to have a smaller capacity for water vapor and also cause the removal under proper circumstances of much of the water vapor by condensation, producing a minimum of vapor pressure and absolute humidity near the ground just before dawn. This is the so-called secondary minimum.

As the sun rises, it warms the ground and evaporates much moisture. The lapse rates at first are insufficient to cause much instability hence the vapor pressure rises to the primary maximum occurring between 6 and 9 a. m. The "nocturnal inversion" frequently found not far above ground also aids by acting as a sort of ceiling to prevent the moisture from diffusing rapidly aloft. When the sun gets higher, the lapse rates increase near the ground, and often the "nocturnal inversion" disappears or rises higher in a less marked state. Thus convection becomes active, carrying much water vapor away from the ground layers. By the time the afternoon maximum of temperature has been reached, the supply of surface ground water has been greatly depleted and the rate of evaporation from the ground has become less than the rate at which the ascending air currents and eddies carry the moisture aloft. Hence we have the primary minimum of vapor pressure (and absolute humidity) at the surface occurring about mid-afternoon in the summer at inland stations. The evening (secondary) maximum occurs as a result of the rapid subsidence of air at dusk or shortly thereafter when convection has greatly diminished, and also as a result of the comparatively small decline in temperature near the ground.

Tropical stations in general present the characteristics described above all the year round.

Over the ocean in summer and winter the sun does not warm the water very rapidly and the diurnal amplitude of temperature is small, hence no rapid increase of evaporation can take place immediately after dawn and the morning maximum is absent. As the altitude of the sun increases, the rate of evaporation increases. Since an indefinitely large supply of water is available, and for other less important reasons not presented, the evapora-

tion can provide more water vapor than is removed. Hence we have an afternoon maximum. The evening maximum is also absent, here largely because the great ocean mass and slow change of water temperature prevent marked changes in surface evaporation, and decrease the tendency for sudden subsidence. The minimum occurring before dawn results from nocturnal cooling of the surface water and lower strata of air. Coastal and island stations are greatly influenced by the ocean and in general show the same type of diurnal march of surface vapor pressure.

At inland stations in winter the diurnal amplitude of temperature is usually comparatively small; and generally a considerable amount of surface ground water is available, either in the form of a snow-cover or ground frost. Also, inversions are quite prevalent over many temperate stations in winter (see Table 14), persisting in some cases throughout the day. These factors, and others, combined with the low altitude of the sun conduce to a slow and often small increase of vapor pressure at the surface from dawn to the afternoon maximum. Convection being relatively weak, the surface supply is little depleted thereby. The evening subsidence is comparatively less marked than in summer and ground temperatures are quite low, hence the evening maximum does not occur. The early morning minimum is caused by the same processes as were previously described.

With regard to mountains, the diurnal variation is similar to that of the free air some distance above the ground. Thus, convection carries moisture up the mountain sides from the valleys in the afternoon at about the time the sun is most effective in producing evaporation from the ground water and vegetation on the mountain slopes. Hence the maximum occurs in the afternoon, and the minimum before dawn when radiation has brought about considerable cooling and much of the moisture has been carried down by subsidence.

On low hills it is possible for the valley effect to preponderate over the free-air effect and the diurnal variation of surface vapor pressure thereon to resemble somewhat that of the valley.

Similarly the vapor pressure in the free air has a periodic diurnal variation. The data presented by Hann (loc. cit. p. 253) for the diurnal march of vapor pressure on mountain tops shows that for moderate heights (2,700–3,700 m.) there is a maximum occurring between 1 and 5 p. m. in the afternoon and a minimum occurring in the early morning from 2 to 6 a. m. With regard to the diurnal variation of absolute humidity over Mount Weather, 526 m. above sea-level and 374 m. above the valley floor (**16**), Blair (**17**) has stated that—

> With the exception of the surface and 1-kilometer levels in the summer half of the year and the 2.5 and 3 kilometer levels in the winter half of the year, the maximum moisture content of the air is found shortly after noon and the minimum shortly after midnight at all levels (526–3,000 m.) and in all times of the year. At the four levels mentioned the maximum moisture content is found just before noon.

An examination of the curves of the diurnal variation of absolute humidity over this place shows that a close approximation to the mean value for the day prevails between the hours 7 to 10 a. m., i. e., the time of day represented by the data given in Tables 2, 3, and therefore most probably also Table 7. This is also borne out by Süring's data (**2**, p. 162) from balloons and Hann's data from mountain stations.

It is evident from the foregoing that for a low-lying station in summer if the total amount of water vapor in a column of air of given cross-section is greater in the early afternoon than in the period 7 to 10 a. m., and also the surface vapor pressure is less in the early afternoon than in the morning, then the factor F_{0}^{∞} applicable to the afternoon should be greater than that for the morning. In winter, since the surface maximum of vapor pressure falls in the afternoon, the opposite of this may be true, particularly where a snow cover exists. Likewise for mountain stations, either of these conditions may obtain, depending on the height, since if the mountain is sufficiently high the maximum surface vapor pressure occurs in the afternoon. This then introduces another source of error in the use of the factors given, indicating that both diurnal and altitudinal corrections are necessary where they are to be used for times and heights other than those for which the data apply.

To obtain an approximate quantitative idea of the error arising from diurnal variations, the data presented by Blair (loc. cit.), for Mount Weather, Va., showing the diurnal variation of temperature and absolute humidity for the surface (526 m.), and the levels for every 500 m. interval from 1,000 m. to 3,000 m. inclusive, all above sea level, were used to compute the respective values of F_{526}^{3000} for two seasons and two times of day each. The seasons given were summer, represented by the 6-month period April–September inclusive, and winter, represented by the period October–March inclusive. Table 9 shows the results of the computations.

TABLE 9.—*Diurnal variation of F., Mount Weather*

Summer		Winter	
Time of day	F_{526}^{3000}	Time of day	F_{526}^{3000}
8:30 a. m.	1,251	8:30 a. m.	1,434
4:00 p. m.	1,389	3:00 p. m.	1,392

The earlier times of day used are closely representative of the average time of flights upon which the data given herein are based. The later times are approximately the times of maximum water-vapor content of the air column in question. A comparison of the values shows that in summer the value F_{526}^{3000} is 11 per cent greater at the afternoon maximum, and in winter 3 per cent less than at the 8:30 a. m., average condition. Since the vapor pressure at Mount Weather is tempered somewhat by the free air overlying the adjacent valleys, it is to be expected that a valley station would find the corresponding afternoon value more than 11 per cent greater in summer and not quite 3 per cent less in winter.

As is to be expected, the diurnal variation of absolute humidity is relatively small at 3,000 m. and probably is vanishingly small at 6,000 m. On this account the actual diurnal variation in F_{0}^{∞} during summer at a valley station may be expected to be slightly smaller than the above value or of the same order of magnitude. This is also true for winter but to a much greater extent.

In the case of stations situated on fairly high mountains, the vapor content of the air column may average only slightly more in the afternoon than in the early morning. However, increased vapor content in the free air, increased evaporation from the mountain sides with increased insolation, and forced convection of humid air up the slopes during the afternoon cause the surface vapor pressures in such cases to be disproportionately high compared to the free air some distance away. It is

thus obvious that the F_s^∞ for the afternoon under such circumstances averages lower than for the early morning (11). Since this is contrary to what obtains at valley stations in the summer, levels must exist at which the variations in the factor are comparatively negligible on the whole, particularly on mountain slopes. In this connection we may note that the mean value of F_{1730}^∞ found by Fowle for the late morning observations at Mount Wilson was but 73 per cent of the early morning value. These values were based on days during the summers of 1910 and 1911 when spectrobolometric observations were made (11).

In conclusion of this topic it may be said in the absence of other data that the factors F_s^h given herein are unsafe for use at mountain stations. For valley or plain stations at heights comparable to those of the eight base stations used, corrections for diurnal variation and height are necessary. It may be suggested that during the warm part of the year a diurnal correction be used, assuming tentatively say a 12 per cent increase in F_s^∞ at the afternoon maximum (3 to 4 p. m.), over the 8:30 a. m. average value, using proportionate amounts for intermediate times, if values for these times be desired. In the

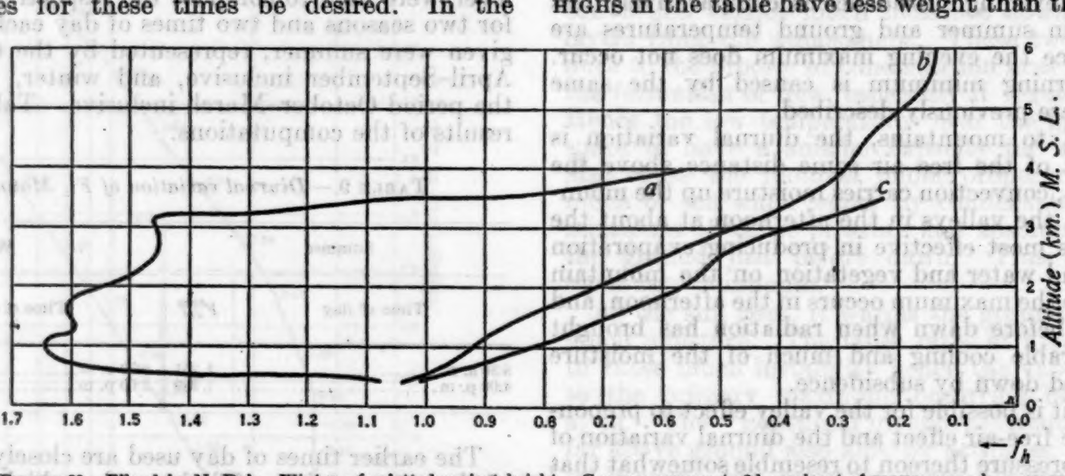

FIGURE 20.—Ellendale, N. Dak. Winter. f_h plotted against height. Curve a represents 2d quadrant of HIGHS; curve b, average of all sorts of conditions for the entire season; curve c, 3d quadrant of LOWS

spring and autumn when convection is weak a smaller value than the above should be assumed, perhaps 5 per cent. In winter, the diurnal correction may be neglected or be assumed to have a small negative value (say 2 per per cent at the afternoon maximum), especially when the ground is rather moist. Southern stations in summer may have slightly larger values than the above.

Stations situated on slightly elevated terrain should use slightly smaller values than those given above.

(c) *Transient variations with weather types.*—The laws governing the genesis of the macroscopic meteorological systems of the atmosphere, the cyclone and anticyclone, in some manner not entirely clear, condition the relationships between the various meteorological factors to be observed in their vertical cross-sections, so as to bring about wide divergencies. This is particularly true of the relative vapor content found from level to level in a vertical section of the lower troposphere. To emphasize this point we reproduce in Figures 20–22, inclusive, curves of the function f_h as computed from mean vapor pressures and temperatures observed in different quadrants of well-pronounced HIGHS and LOWS at several stations. Sets of curves were chosen which showed the widest divergence in this respect among all the curves available from Samuels's study of aerological observations made in well-pronounced HIGHS and LOWS (18).

The curves representing the average for all types of conditions are also shown by way of comparison. It is noteworthy that the curves for summer do not show such marked differences as found for the winter curves. Table 10 shows the comparative values of the integrals F_s^h for the curves given in figures 20–22, and also mean surface vapor pressures for each case.

TABLE 10.—*Examples of widely divergent values of F_s^h for special weather types in winter*

Station	Well-pronounced LOWS			Average of all types		Well-pronounced HIGHS			h
	Quadrant	$\bar{e}_s$	F_s^h	$\bar{e}_s$	F_s^h	Quadrant	$\bar{e}_s$	F_s^h	
		mb.		*mb.*			*mb.*		*m.*
Drexel, Nebr. (s=396 m.)	4	6.00	1,640	3.66	2,210	3	2.64	3,060	4,000
Ellendale, N. Dak. (s=444 m.)	3	3.57	1,850	2.56	2,170	2	1.09	4,580	3,500
Royal Center, Ind. (s=225 m.)	1	6.13	2,490	4.32	1,680	3	3.85	1,220	3,000

It should be noted that the values under LOWS and HIGHS in the table have less weight than the values in the central columns, mainly since they are based on fewer observations than the latter.

We may conclude from these values, however, that the transient variations of F^h are likely to be of such magnitude that serious errors may result if one attempts to compute the amount of water vapor in an air column at a particular moment from the average values of F_s^h given. This is most probably more true in winter than in summer. The use of average values may be safe for computing the average vapor content of the air column over a period of perhaps a season where a normal sequence of weather changes has occurred. In such cases the mean surface vapor pressure for the period must be used.

(d) *Errors due to sampling.*—As with every set of statistical variables where relatively few samples are taken for study, some uncertainty in the data must exist. Since the monthly means upon which the results are based were not in convenient shape to compute the probable errors, this index of the reliability of the means is not available. In all cases with the exception of the airplane flights at Washington, D. C., the means of ascent and descent were used. This method takes the diurnal variation into account and renders the final results more reliable. As stated before, where the observations are quite numerous as may be seen is the case for the lower levels at most of the stations (see Table 2), the results may be considered fairly reliable as averages.

Several sources of error due to sampling creep in however. Thus for example, since a certain minimum surface wind velocity is necessary before kites may be launched, it is to be expected that calm days are not well represented in the results. This is most likely to be true for the summer and autumn data and most pronounced in southern stations where more days of calm prevail during those seasons. This same effect causes the results to be less reliable in the upper levels for these seasons. Likewise, days of very strong winds are not fairly represented in the data. This is likely to be most effective at northern stations during winter and early spring. The former source of error is not present in the case of airplane observations.

In addition to the above, days of heavy or moderate rain or snow are not represented in the data. Days of low overcast sky are also lacking from the airplane data, as are data for the interior of deep banks of clouds. Kite observations on the contrary frequently provide such results.

The fact that the highest kite and airplane observations were probably made on relatively dry days brings to bear a systematic error of uncertain magnitude in the values for the higher levels.

Since nothing definite may be said regarding the magnitude of the errors arising from the above sources, it is necessary to leave the matter standing. It is felt however, in the case of kite stations where observations are numerous that the errors, if important at all, are only worth considering in the southern stations during the summer and perhaps the autumn seasons. The airplane data for Washington, D. C., are probably more nearly representative on the whole of fair and partly cloudy conditions.

(*e*) *Errors in observed values.*—As is well known, the hair hygrometers such as are used in kite, airplane and sounding balloon meteorographs are somewhat erratic in their behavior and are often subject to considerable errors. The most important source of error is probably that due

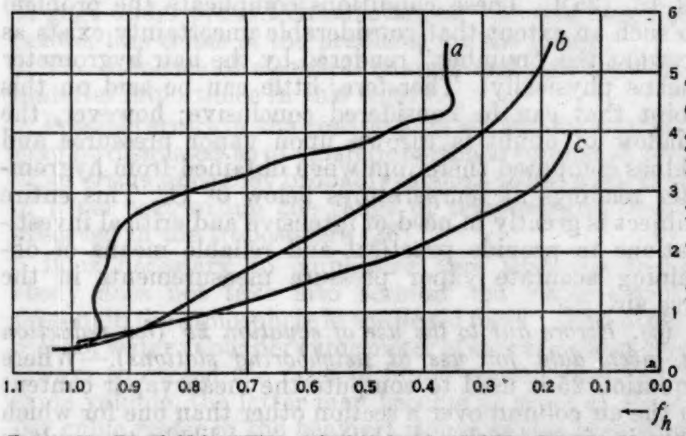

FIGURE 21.—Drexel, Nebr. Winter. f_h plotted against height. Curve a represents 3d quadrant of HIGHS; curve b, average of all sorts of conditions for the entire season; curve c, 4th quadrant of LOWS

to the effect of the lag or inertia of the hygrometric element. The investigation of Kleinschmidt (4), on this phase of the question brought him to the conclusion that the factors which cause the greatest increase in the sluggishness of the element are: (*a*) Low temperature, (*b*) low humidity, especially when the difference between the actual and recorded humidities is small, (*c*) rapid rate of change of humidity with time as regards the instrument, (*d*) large number of hairs used in the element, (*e*) poor or unequal ventilation, (*f*) poor quality or treatment of hairs. By far the most important factor of these seems to be temperature, for it is stated (loc. cit.), that—

The temperature effect on the lag is small between +20° and +5° C.; from that temperature however, it increases rapidly, becoming infinitely great at −40° C., and almost completely reducing to nought the ability of hair to react to water vapor.

Despite objections recently raised to Kleinschmidt's methods (19), there is not much doubt that below −40° C., the hairs used, function more as a thermal element than a hygrometric element. This conclusion is amply supported by the indications of sounding-balloon observations.

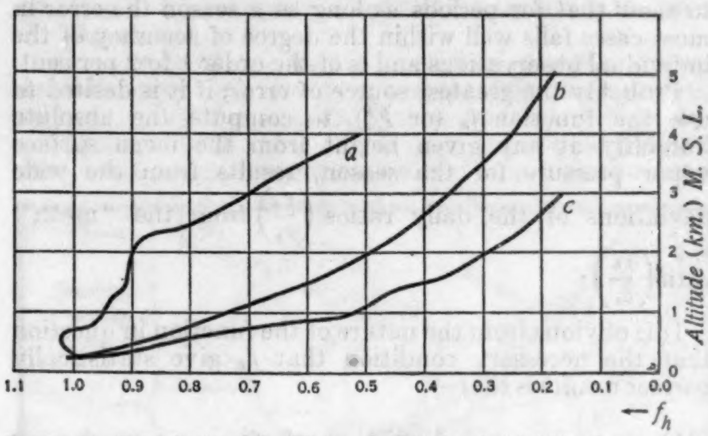

FIGURE 22.—Royal Center, Ind. Winter. f_h plotted against height. Curve a represents 1st quadrant of LOWS; curve b, average of all sorts of conditions for the entire season; curve c, 3d quadrant of HIGHS

It should be remembered, however, that meteorological kites rise much more slowly on the average than either airplanes or sounding balloons and hence the hygrometric elements have a much longer time available in which to respond to the humidity of the air than is the case for the latter methods of observation.

The lag of the temperature element is quite small in the kite instruments used (20), hence mean vapor pressures based on kite observations probably are more reliable than any others extant, except possibly those obtained from manned balloons and carefully conducted airplane observations. Even here, however, they must be sufficiently numerous to form a satisfactory basis for reliable results. This feature of the problem causes the values for Leesburg, Ga., to be of much less weight than the remainder of the values, since the observations taken at that place were relatively few. Likewise the values for high levels, especially in winter and early spring, are probably much less reliable owing to the temperature effect.

(*f*) *Errors due to methods of computing results.*—As stated in a previous section (III), the method of differences has been employed in computing mean monthly vapor pressures and temperatures. Since vapor pressure does not vary linearly with height, it is problematical whether that method is the proper one to use in obtaining means of that variable.

A consideration of the effects of the use of this method leads to the conclusion that if in the long run the higher observations are made on relatively dry days, as is quite likely, the computed mean vapor pressures for the higher levels will tend in the long run to be *higher* than the true means. The proper method to use is one based on the indications of the Theory of Probability and Errors considering the nature of the law of variation of vapor pressure with height. Thus far no satisfactory method that does not involve a prohibitive amount of work has been suggested, as far as known.

We thus have from these sources, errors due both to the method of computing and to a systematic limitation on sampling of data under all conditions.

In addition, another possible source of error may lie in the fact that the absolute humidity computed from the arithmetical mean of the daily observed absolute humidities for any given period may differ from the absolute humidity computed from the mean vapor pressure and temperature respectively for the same period (**21**). An examination of data for a number of months taken at random appears to show that for periods as long as a season the error in most cases falls well within the degree of accuracy of the individual observations and is of the order 1 to 2 per cent.

Probably the greatest source of error, if it is desired to use the function f_h (or F^h_s), to compute the absolute humidity at any given height from the mean surface vapor pressure for the season, results from the wide deviations of the daily ratios $\left(\frac{e_h}{e_s}\right)$ from the "mean" ratio $\left(\frac{\bar{e}_h}{\bar{e}_s}\right)$.

It is obvious from the nature of the function in question that the necessary condition that f_h give statistically correct results is that—

$$f_h = \frac{1}{n}\,\frac{273}{\frac{1}{n}\sum_{i=1}^{n} e_{s_i}} \cdot \sum_{i=1}^{n} \frac{e_{h_i}}{T_{h_i}} \tag{31}$$

where T_{h_i} = absolute temperature at height h, for the i-th observation and n = number of observations, the other symbols being as defined before, and the observations equally spaced in time. Tests on data for a number of seasons taken at random showed that percentage errors in the lower kilometer are usually quite small but are likely to increase above that height. For periods as short as a month the errors from this source may be very large for heights 2,000 m. above sea level and higher. In one case, viz, for March, 1926, at Ellendale, N. Dak., this error at the 3,000 m. level was 24 per cent of the average of the 16 observations available. When data for a full season are examined and compared, the percentage error resulting from the use of f_h for a height of say 3,000 m is found usually to fall within 7 per cent. Probably the errors would be quite serious for heights above 4,000 m.

Another source of errors falling within this category (f) is that arising from the use of hair hygrometer humidity readings and tables of saturation vapor pressures to compute current vapor pressures. In this method, the saturation vapor pressure corresponding to the observed current temperature is obtained from tables and multiplied by the relative humidity reading to give the current vapor pressure. For temperatures below 0° C., the tables used are those for the pressure of aqueous vapor over ice, while for temperatures above 0° C., the tables used are for vapor pressures over water. This arbitrary rule even though justified by expediency may be improper for use in the free air since for example water droplets may exist in the free air at temperatures far below the freezing point (**22, 23**). Thus, the hair hygrometer, calibrated at room temperature, when taken into the free air, yields a "number" which we call the "relative humidity." The definition of the latter term depends upon the form and kind of surface, whether water or ice, to the saturation vapor pressure of which at the given temperature we refer the actual vapor pressure to obtain the relative humidity. If for every case where temperatures below 0° C. are observed, we use the saturation vapor pressure over a flat surface of ice as the standard, and if liquid water is present in the atmosphere under the given temperature, then it is obvious that the "number" taken as the "relative humidity" may give erroneous results.

The following figures are illustrative. From the Smithsonian Physical Tables, seventh revised edition, we find for −16° C.,

1.315 mm. Hg. = saturation vapor pressure over water.

1.142 mm. Hg. = saturation vapor pressure over ice.

For 100 per cent relative humidity at this temperature with respect to water, the relative humidity with respect to ice is

$$\frac{1.315}{1.142} \times 100 \text{ per cent} = 115.1 \text{ per cent.}$$

For −30° C., Robitzsch (**24**) finds the corresponding value to be 133.2 per cent. It is obvious from these figures that if the "number" obtained from the hair hygrometer represents the relative humidity with respect to water, say at −16° C., then this "number" must be multiplied by 1.15 to obtain the relative humidity with respect to ice. In other words the vapor pressure computed as in the past from the tables for the saturated vapor pressures over ice will be 15 per cent too small under these circumstances.

The above considerations are strictly applicable only for pure substances. However, water droplets in the free air are nearly spherical and contain hygroscopic nucleii which lower the vapor pressure. The importance of these nucleii in the mechanism of undercooling of water droplets has been much emphasized by Köhler (**22**). In addition, undercooled water particles of such smallness that they are invisible must exist in the atmosphere under certain circumstances and probably are quite prevalent in the vicinity of clouds [(**22**) (b) pp. 13–15, (**25**)]. These conditions complicate the problem to such an extent that considerable uncertainty exists as to what the "number" rendered by the hair hygrometer means physically. Therefore, little can be said on this point that can be considered conclusive; however, the shadow of doubt is thrown upon vapor pressures and values computed therefrom when obtained from hygrometer readings at temperatures below 0° C. This entire subject is greatly in need of intensive and critical investigations to provide practical and reliable means of obtaining accurate vapor pressure measurements in the free air.

(*g*). *Errors due to the use of equation 25 (for reduction of given data for use at neighboring stations).*—Where equation 25 is used to compute the mean vapor content in the air column over a section other than one for which data is given herein, the largest error likely to result is that due to geographical interpolation. Thus, values S computed from the three nearest "datum stations" may show a considerable difference. This necessitates that the values be weighted according to climatological and physiographic considerations and also according to distance and direction of each station from the others. The percentage error arising from this source is obviously variable and depends somewhat upon the intimacy of the person using the formula with the nature of the region with which he is concerned. It may be mentioned here that a defect to be found in *all* formulas of this sort is that they can not take into account local or geographical variations.

The data given herein are therefore most advantageous for use in central and eastern United States since some cognizance may then be taken of these factors.

Other errors associated with the use of this equation depend on the differences between the absolute humidities existing in the free air over the "datum station" at given heights above sea level and those existing at the same heights above sea level over other stations. Several computations have been made to ascertain the magnitude of this error, using certain assumptions based on observational data. The percentage errors in these cases were found to be less than 3 per cent where the upper base of the column was as much as 5,000 m. and where $x=750$ to 1,500 m. above sea level.

Uncertainty regarding the most applicable value of the constant in Hann's equation, 8, likewise introduces the possibility of a further error. However, the value used (6,300) is considered to be the best value extant for this purpose, firstly, because it is based on mountain observations, and secondly, because it agrees well with values obtained from the data for the lowest kilometer over the stations used herein.

(h) *Miscellaneous errors.*—Among these may be mentioned (*a*) errors in the determination of e_s or e_x, (*b*) errors due to the effect of hygroscopic particles in the atmosphere, (*c*) error in the constant K depending on variations in the relative density of atmospheric water vapor to pure dry air.

As is well known, serious psychrometric errors may arise during the winter when subfreezing temperatures prevail, hence the surface vapor pressures must be determined as accurately as possible to reduce the error to a minimum.

Regarding hygroscopic particles, it may be said that very little is known as to their effect on hair hygrometers and errors resulting therefrom. In general it may be seen that hygroscopic nuclei permit of a larger moisture content in the air than would appear possible from theoretical considerations which disregard their presence (22). This brings in an error whose magnitude it is difficult to gage under present circumstances. As was mentioned before, this is one of the problems for the future.

The influence of electrical charges and ions may be of material importance in this regard.

Possible errors in the constant $K(=1.060$ for e_s in mm.) may be dismissed as of small importance compared to the other errors since they probably amount to but a few tenths of a per cent within the range of temperatures thus far observed in the troposphere (26).

It is necessary to emphasize here that the present study does not take into account the water which is present in the atmosphere in the liquid form. Although the mass of water vapor per cubic meter of cloud has been found always to exceed the mass of liquid water present in the same volume, the latter may become as great as 5 grams per cubic meter in the heaviest clouds as has been shown by the independent investigations of Conrad, Wagner, and Köhler (27).

VI. COMPARATIVE STUDY OF THE DATA

1. *The function* $f_h=\left\{\dfrac{\left(\frac{e_h}{e_s}\right)}{1+\alpha t_h}\right\}$.

(*a*) *Seasonal variation.*—A study of the values of f_h given in Table 2 shows that on the average the values are greatest in winter and least in summer, and usually for heights greater than several hundred meters above ground the autumn values are greater than the spring values. Also, it may be seen that the values for summer for certain levels (usually above 1.5 km.) are greater than the values for spring. In southern stations where this is most pronounced, the summer values even exceed the autumn values for certain levels.

The interpretation of the statement that f_h for a given level is greater for one season than for another is that the absolute humidity at that level is greater on a day during the first season than on one during the second season where the vapor pressure at the surface is the same in both cases.

The contrasts between the various seasonal values depend partly upon the temperature differences existing and partly upon actual changes in relative vertical distribution of water vapor. It is evident from the gas laws that for a given vapor pressure the vapor content of a given volume is greater at low temperature than at high temperature.

FIGURE 23.—Geographical locations of the eight stations used herein

If the ratios $\frac{f_h}{f_s}$ be formed from the data given in Table 2, it will be seen that the ratios are greater in winter than in summer at the four stations Drexel, Ellendale, Groesbeck (note below), and Washington, D. C. The reverse is true for certain intervals of height at the other stations. The intervals where $\left(\frac{f_h}{f_s}\right)_{\text{summer}}>\left(\frac{f_h}{f_s}\right)_{\text{winter}}$ are:

Broken Arrow, from 250–500 m. to 2,000–2,500 m.
Due West, from 2,000–2,500 m. to beyond 4,000 m.
Groesbeck, from surface–250 m. to 500–750 m.
Leesburg, from surface–250 m. to beyond 4,000 m.
Royal Center, from surface–250 m. to 1,500–2,000 m.

It will be noted that Groesbeck shows this effect only slightly and that the winter ratios are greatest at stations where in general the winter inversions are most pronounced (see figs. 20–22, and also ref. (18)). Referring back to Section V, 2 (*a*), p. 461, a number of causes operating to produce this relationship in inversions have been discussed.

It may be added here that when convection and turbulence are most active, i. e., when lapse rates are near the

adiabatic, the water vapor distribution naturally shows a more nearly uniform manner of decrease with height than when inversions are present. In the latter case the tendency is for the water vapor to stratify within or just below the inversion and to show a sharp decrease just above it. We should therefore consider these factors as among the most dominant in producing the downward march of the water content of the upper troposphere from summer to winter and its concentration in the lower few kilometers in the latter season, particularly in regions farthest removed from the Equator.

(*b*) *Geographical variation.*—Since the stations used herein are not of equal elevation and since the periods of observations upon which the present data are based are not identical, nor, of equal length, nor of very great duration, comparisons between the several stations must be taken with some reservations. Such comparisons with respect to vertical position should, strictly speaking, be comparisons between data for equi-geopotential surfaces (28), or possibly even surfaces of equal gravity potential above ground. Unfortunately, reduction of the data to such surfaces involves a large amount of additional labor. Such reductions are of course more important for high levels and for extensive latitudinal differences, but since the reliability of the data scarcely justified this refinement they were not undertaken.

The latitudinal variation of f_h may be seen by a comparison of the data for Ellendale, Drexel, Broken Arrow, and Groesbeck in order. The function shows a progressive decrease from north towards south at all levels in the lower 3–4 or so km. over these stations. Above these heights the relationship is not so consistent but signs of a reversal are evidenced. Comparing the data for Washington, D. C., and Due West, it would appear that f_h for the former is less at all levels during the summer and autumn, while during the other two seasons it is less only in the lower few kilometers but is greater above that height. Likewise, comparing Due West and Leesburg (data least reliable), it would appear that the data for Due West are greater at all levels in autumn and winter. During spring and summer however, f_h for the former is only greater from the surface to 2.5–3.0 km., the opposite being true above these heights.

Something regarding the longitudinal variation may be seen by comparing Drexel with Royal Center, Royal Center with Washington, Broken Arrow with Due West, and Groesbeck with Leesburg. Values of f_h at Drexel are found to be greater than those at Royal Center at all levels and all seasons. The relationship between Royal Center and Washington values is more complex. Speaking in general, the values at the former station are greater in the lower layers (surface to 750–2,500 m. depending on season), then the reverse is true for a thousand or more meters, and finally there is some evidence that at greater heights the Royal Center values are again greater.

Considering Broken Arrow and Due West, during summer and autumn for heights beyond the lower half kilometer or so, the Due West values of f_h appear greater than the Broken Arrow values. During the other two seasons, this is only true to heights between 2.5–3.0 km., a reversal of the relationship appearing above these limits. Groesbeck values show themselves to be greater than the Leesburg values in the lower kilometer or so (roughly speaking) but less above these heights in all seasons except autumn which has a more complex connection.

The interpretation of such relationships as are described above has already been given in the preceding section (*a*). Attention is invited to the fact that the values of f_h particularly for the lower levels appear to be smaller for stations near bodies of water than for inland stations considerably removed therefrom. This relationship is most pronounced in the North. This circumstance may be largely due to other local conditions [1] and hence must be investigated further to obtain verification or disproof of such a general conclusion.

2. *The average absolute humidity aloft.*—$\overline{W}_h = K\bar{e}_s f_h$, *g./m.*^{3}

(*a*) *Seasonal variation.*—Table 11 has been computed according to the above equation from data given in Table 2.

TABLE 11.—*Geographical and seasonal variation of absolute humidity* (*g./m.*^{3})

SPRING

Height above sea level (m.)	Ellendale (444 m.)	Drexel (396 m.)	Broken Arrow (233 m.)	Groesbeck (141 m.)	Royal Center (225 m.)	Washington (7 m.)	Due West (217 m.)	Leesburg (85 m.)
Surface	4.90	6.32	9.11	11.51	6.77	7.44	9.10	11.10
250	—	—	9.03	11.06	6.67	6.74	8.96	10.26
500	4.77	6.01	8.02	9.99	5.81	6.02	8.02	9.33
750	4.22	5.35	7.23	9.05	5.23	5.39	7.32	8.59
1,000	3.84	4.86	6.61	8.03	4.75	4.95	6.75	7.93
1,250	3.52	4.41	5.94	6.97	4.29	4.58	6.19	7.27
1,500	3.22	3.99	5.28	5.94	3.89	4.27	5.59	6.54
2,000	2.65	3.25	4.16	4.40	3.19	3.53	4.40	4.84
2,500	2.16	2.69	3.30	3.48	2.47	2.82	3.37	4.14
3,000	1.72	2.24	2.68	2.86	1.95	2.21	2.56	3.36
3,500	1.37	1.83	2.21	2.36	1.57	1.80	1.97	3.04
4,000	1.07	1.49	1.77	1.99	1.27	1.36	1.58	2.78

SUMMER

Height above sea level (m.)	Ellendale (444 m.)	Drexel (396 m.)	Broken Arrow (233 m.)	Groesbeck (141 m.)	Royal Center (225 m.)	Washington (7 m.)	Due West (217 m.)	Leesburg (85 m.)
Surface	11.74	13.84	16.84	18.26	13.68	15.84	16.17	17.89
250	—	—	16.70	17.70	13.51	14.46	15.95	16.71
500	11.40	13.09	14.94	16.19	11.99	12.92	14.39	15.48
750	10.05	11.57	13.51	14.29	11.02	11.66	13.23	14.67
1,000	9.09	10.53	12.34	12.43	10.20	10.60	12.25	13.55
1,250	8.25	9.62	11.21	11.03	9.32	9.69	11.26	12.27
1,500	7.44	8.71	10.13	9.86	8.37	8.96	10.25	10.92
2,000	6.05	7.12	8.16	7.95	6.51	7.54	8.39	8.84
2,500	4.99	5.77	6.46	6.49	4.84	5.95	6.85	7.27
3,000	4.04	4.66	5.18	5.33	3.68	4.51	5.56	6.47
3,500	3.32	3.76	4.15	4.39	2.79	3.45	4.60	5.63
4,000	2.74	2.99	3.30	3.62	2.16	2.52	3.73	5.14

AUTUMN

Height above sea level (m.)	Ellendale (444 m.)	Drexel (396 m.)	Broken Arrow (233 m.)	Groesbeck (141 m.)	Royal Center (225 m.)	Washington (7 m.)	Due West (217 m.)	Leesburg (85 m.)
Surface	5.83	7.27	10.19	12.80	8.51	10.18	10.34	13.47
250	—	—	10.12	12.36	8.42	9.29	10.18	12.73
500	5.72	6.97	9.14	11.30	7.55	8.49	9.23	11.82
750	5.22	6.31	8.31	10.31	6.91	7.79	8.48	10.90
1,000	4.77	5.78	7.64	9.23	6.27	7.23	7.88	9.92
1,250	4.33	5.29	6.97	8.19	5.65	6.68	7.21	9.04
1,500	3.93	4.84	6.25	7.29	5.05	6.12	6.55	8.00
2,000	3.26	4.04	4.84	5.61	3.99	4.93	5.20	5.95
2,500	2.73	3.36	3.71	4.32	3.14	3.81	4.14	4.36
3,000	2.27	2.77	2.88	3.31	2.52	2.83	3.41	3.34
3,500	1.85	2.25	2.28	2.64	2.02	2.08	2.88	2.62
4,000	1.51	1.87	1.66	2.06	1.46	1.42	2.45	2.33

WINTER

Height above sea level (m.)	Ellendale (444 m.)	Drexel (396 m.)	Broken Arrow (233 m.)	Groesbeck (141 m.)	Royal Center (225 m.)	Washington (7 m.)	Due West (217 m.)	Leesburg (85 m.)
Surface	2.11	2.96	4.75	7.13	3.47	3.85	5.99	7.60
250	—	—	4.71	6.84	3.41	3.59	5.92	7.09
500	2.07	2.82	4.21	6.24	3.03	3.30	5.39	6.44
750	1.95	2.59	3.78	5.72	2.77	3.09	5.04	5.97
1,000	1.88	2.44	3.42	5.12	2.51	2.86	4.70	5.45
1,250	1.81	2.32	3.07	4.59	2.27	2.65	4.33	4.95
1,500	1.70	2.17	2.76	4.05	2.06	2.45	3.93	4.46
2,000	1.45	1.87	2.23	3.17	1.69	2.09	3.19	3.43
2,500	1.22	1.59	1.85	2.57	1.44	1.76	2.51	2.82
3,000	0.97	1.34	1.56	2.09	1.24	1.42	1.99	2.32
3,500	0.74	1.10	1.34	1.70	1.04	1.14	1.58	1.68
4,000	0.59	0.87	1.14	1.45	0.86	0.95	1.30	1.23

Comparison of the data by seasons shows that there is a progressive increase in absolute humidity from winter to summer and that the autumn values exceed the spring values at all the stations and for almost all the levels given. The levels 4,000 m. at Broken Arrow and 3,000–4,000 m. at Leesburg stand as exceptions (note data for latter station not very reliable).

(*b*) *Geographical variation.*—Figure 23 indicates the geographical location of the eight stations used. Com-

[1] See discussion on p. 455, Section IV, 2, regarding low temperature in the free air along the Atlantic Coast.

parisons of the stations presented in the first four and last three columns of Table 11 indicate the progressive increase of absolute humidity on going from north to south at all levels given. Broken Arrow, 4,000 m., autumn; Leesburg, 3,000–4,000 m., autumn; and Leesburg, 4,000 m., winter, stand as exceptions. The Leesburg values being based on few observations, are not very reliable and hence these exceptions are to be taken with reservations.

Comparing Drexel and Royal Center we find the values for the former to exceed those for the latter at all levels above 500 m. in spring, and at all levels in summer. During autumn the Drexel absolute humidities are less than the Royal Center absolute humidities from the surface to between 1,500–2,000 m. Above that height the Drexel values are greater. In winter the same relationship exists, only the height at which the reversal takes place lies between 1,000–1,250 m.

The relationships last presented appear anomalous at first sight, for one would be inclined to think that the proximity of Royal Center to Lake Michigan would render it more moist aloft than an inland station far removed from the lake and almost equidistant from the Gulf of Mexico. However, they may be traced back to the pressure gradients which normally exist over continental United States, and to the resulting air flow from different origins. Referring to Gregg's **(29, 6)** Aerological Survey of the United States (Mo. Wea. Rev. Supp. 26, pp. 55–56 and Supp. 20, pp. 39 and 45) it will be seen that in summer and spring the normal pressure gradients cause the resultant winds over Drexel to have a considerable southerly component while the resultant winds at Royal Center are more from the west and west-northwest. This brings about a greater transport of moist gulf air to Drexel than to Royal Center, and the latter must get a larger proportion of the relatively dryer polar air **(30)**. In winter and autumn the resultant winds at Drexel have a more northerly component than those for Royal Center and the relationship is partly reversed.

Comparisons of Royal Center with Washington, Broken Arrow with Due West, and Groesbeck with Leesburg bear out remarkably well on the whole what would be expected from considerations of the resultant air flow.

These facts emphasize the importance of studying the movement of air masses more closely **(30)**, both for forecasting purposes and for the study of comparative climatology.

3. *The integral,* $F_s^h = \int_s^h f_h dh$.—

(*a*) *Seasonal variation.*—Considering the values given in Table 3, it will be noted that the winter values are the largest. In northern stations the summer values are always least for the data given. In southern stations the summer values differ little from or exceed the spring values for h generally above 2,500 m., the summer values being less for h below that approximate height. Leesburg appears to show this difference at even lesser heights. The autumn values exceed the spring values in every case where the data are relatively reliable. Leesburg above 3,000 m. may be an exception.

The interpretation of a statement that F_s^h for one season exceeds the corresponding value for another season is that on days when the surface vapor pressures are the same in both seasons, the day in the first season will have a larger total vapor content, S^h_s, in the air column from the surface to height h than will the day in the second season.

Some of the underlying causes of the differences indicated above have been previously discussed under Section VI, 1 (a).

(*b*) *Geographical variation.*—Since the values of F_h have not been reduced to a common datum surface, they are not strictly comparable. However, since it so happens that the group of stations Ellendale, Drexel, Broken Arrow, and Groesbeck have lower surface elevations above sea level in descending order respectively, some valid conclusions may be drawn from the data given. An inspection of the values for these stations indicates that in the higher levels at least, the values decrease from north to south, despite the opposing effect of decreasing surface elevation in the same direction. Hence it may safely be concluded that if the data were reduced to a common datum surface, the values, for h (the upper limit of the column) equal to say 4,000 m., would decrease from north to south. This is in accord with the general latitudinal variation found for f_h, and is most pronounced in the winter seasons as was found for the latter.

In a similar manner we note that the Drexel values exceed the Royal Center values, particularly for the higher levels.

4. *The average total vapor content of the air column.*—$\bar{S}_s^h = K\bar{e}_s F_s^h$.

(*a*) *Seasonal variation.*—As was found for the seasonal variation of absolute humidities, the values $\bar{S}_s^h$ from Table 3 may be seen to increase from winter to summer, with summer having the maximum values. The autumn vapor content exceeds the spring content in every case. The greatest contrast between summer and winter content is found in northern stations and the least in southern stations. Comparing the values for $h = 4,000$ m. for the various stations, it is seen that the spring content is about 0.5 the summer content in northern stations and slightly more (roughly 0.6) in southern stations. For the same upper limit, the average winter content is about 0.25 the average summer content in northern stations. The proportion increases as one goes southward, being near 0.4 at Groesbeck and Leesburg.

The relatively smaller difference between the vapor content during these two seasons in the southern stations as compared with the northern stations is partly due to the smaller contrast between winter and summer with respect to total solar radiation received at the southern stations as compared with the northern stations (**31**). This produces a smaller amplitude of the mean free-air temperature variation between winter and summer at southern stations as compared with northern stations. This in turn influences the relative capacity of the space for water vapor and also the relative evaporation from water surfaces and the soil. The nearness of the southern stations to bodies of water also brings to bear the tempering effect of the high specific heat and slow rate of cooling of the water.

With regard to the solar radiation received, it must be remembered that even though the intensity of the solar radiation received at the top of the atmosphere per day in summer differs little between stations at latitude 30° and 40° N., the amount received at the ground is markedly greater at latitude 40°, in fact the maximum on June 21 is received at about latitude 48° N. (sea level). This is brought about by the increasing length of day and decreasing vapor content from south to north, in spite of the lower altitude of the sun at midday at northern stations (**32**). It is thus seen that the water vapor blanket which is so effective in depleting the radiation received

at the top of the atmosphere and which must increase towards the Equator as the result of the cumulative effect of more intensive heating, itself must act as a tempering agent to diminish the difference between summer and winter at southern stations. The annual march of cloudiness, the variations of which at most places in temperate latitudes can not simply be attributed to solar radiation, will also be seen to be an important factor.

Despite the greater total radiation received in spring as compared with autumn (at sea level), the total vapor content was found to be greater during the latter season. This is largely the result of the after-effect of the preceding seasons in each case respectively.

The more frequent outbreaks of the relatively dry polar air in winter and spring must also be considered an important factor governing the seasonal variation of the vapor content of the air.

(*b*) *Geographical variation.*—Considering the values given in Table 3 for Ellendale, Drexel, Broken Arrow, and Groesbeck, despite the differences in surface elevation, it may be safely said that the total vapor content, $\bar{S}_s^\infty$, in general increases from north to south, as is well known. This is likewise shown by the stations to the eastward, if some allowance is made for differences in elevation.

Comparing Drexel and Royal Center values, it will be seen that despite the greater elevation of the former, the summer values for Drexel exceed those for the latter station at heights above the layer between 3,500 and 4,000 m. This agrees, of course, with the marked differences in absolute humidity found between the two stations for this season. A close analysis of the spring values for these stations appears to indicate that possibly for some height above 6,000 m. the total vapor content of the column for the former may differ very little from that for the latter, this in spite of difference in elevation. This is not so likely to be true in the autumn and winter. (See tables 7 and 2.)

Broken Arrow and Due West show very small differences in $\bar{S}_s^\infty$ for spring, but the difference becomes more and more marked until it reaches a maximum in winter. This is probably largely due to the seasonal changes in frequency and strength of the free-air winds and their places of origin. Thus in spring the most frequent winds at 1,000 m. above surface at both stations are from the Gulf of Mexico (**29**, p. 43). The summer months show a slightly smaller frequency from the northwest quadrant, with slightly more from the southwest at Due West. The winter months on the other hand at Broken Arrow have their most frequent winds at 1,000 m. from the southwest and northwest, i. e., from relatively dry regions, while at Due West the most frequent winds in this season are from the northwest, west, and southwest. The trajectories of air flow in the lower Mississippi Valley and in the Gulf region show that much of the air reaching the southeastern seaboard of the United States in winter (as well as in summer and spring, to a lesser extent in autumn) must have its origin in the Gulf of Mexico. Hence these circumstances are to be regarded as the secondary causes of the differences to which attention was called.

Groesbeck and Leesburg show similar characteristics, if some allowance is made for differences in elevation.

As was stated before, a factor to be considered in the study of the causes of the seasonal variation of the vapor content of the air column is the question of the frequency of outbreaks of polar air. This is also important with regard to geographical-seasonal variations. Thus in winter, spring, and late autumn outbreaks of continental polar-air are more frequent than in summer, late spring and early autumn. Since Ellendale, for example, is more nearly in the path of such outbreaks than any of the other stations, it is obvious that this cause will bring about a more marked variation in $\bar{S}_s^\infty$ between winter and summer at this station than at any of the others. Drexel and Royal Center are also likewise affected. On the other hand, the southern stations such as Groesbeck, Due West, and Leesburg will be much less affected by this cause, since in general the polar-air will have warmed somewhat by its passage southward, and will have had an opportunity to acquire more water vapor. Furthermore, the track of winter cyclones fed by polar-air is often such as to miss entirely the southern stations.

Hence it appears that the variations noted above may largely be explained in terms of solar radiation and air trajectories, these undoubtedly being conditioned by more basic phenomena such as: The revolution of the earth in its orbit; the inclination of the earth's axis to the plane of the ecliptic; the rotation of the earth about its axis; gravity; the physical properties of water in its various forms, as well as of air and earth; the relative distribution of land and water and other physiographic features; solar radiation, quality as well as intensity, as received at the top of the atmosphere; and others.

With regard to the influence of mountain barriers on the vapor content of the air column, the station which we would expect to be most influenced among those given herein is Washington, D. C. There is some evidence that in spring, summer, and autumn the mountain barrier to the west of that station is quite instrumental in partially depleting the vapor content of the air currents which frequently in those seasons flow up the Mississippi Valley from the Gulf of Mexico and recurve eastward toward the Atlantic Ocean. The same effect is produced in winter but here quite often the supply cut off at low levels is comparatively rich in water vapor at heights above the mountain tops, due to inversions, and hence it appears likely that the contrast in vapor content between this station and one to the west of the mountains would be more striking in the former three seasons than in winter. (Compare figs. 11–13.)

(*c*) *Discussion of* $\bar{S}_s^\infty$.—Table 12, which was computed from the factors F_s^∞ given in Table 7 and the mean surface vapor pressures given in Table 2, shows the (tentative) approximate mean depth of water which would be formed if all the water vapor in the air column from the ground to the limits of the atmosphere were condensed instantaneously and deposited upon the ground. The values are given for each season and are expressed both in centimeters and inches. These values give a relative indication of the mean quantity of water vapor effective for absorbing solar radiation and earth re-radiation.

TABLE 12.—*Approximate mean depth of rain equivalent to total vapor content of air column from surface to outer atmosphere* ($\bar{S}_s^\infty$)

Station	Spring		Summer		Autumn		Winter	
	Cm.	*In.*	*Cm.*	*In.*	*Cm.*	*In.*	*Cm.*	*In.*
Broken Arrow, Okla	[1] 1.99	0.785	3.75	1.478	2.17	0.853	1.12	0.441
Drexel, Nebr	1.44	.569	3.16	1.245	1.80	.708	.80	.316
Due West, S. C	1.96	.773	3.92	1.545	2.50	.984	1.45	.570
Ellendale, N. Dak	1.10	.432	2.71	1.067	1.41	.557	.58	.229
Groesbeck, Tex	2.41	.950	4.12	1.622	2.76	1.086	1.65	.651
Leesburg, Ga	2.48	.976	4.29	1.688	2.97	1.169	1.73	.681
Washington, D. C	1.69	.665	3.49	1.372	2.23	.878	1.00	.394
Royal Center, Ind	1.45	.570	2.90	1.142	1.87	.735	.83	.329

[1] To obtain mass in kg., per column one sq. m. in cross section, multiply depth (in cm.) by 10. To obtain mass in metric tons per column one sq. km. in cross section, multiply depth (in cm.) by 10^4. To obtain mass in short tons (2,000 lbs.) per column one sq. mi. in cross section, multiply depth (in cm.) by 2.855×10^4.

It is clear from the values presented that the blanketing or "greenhouse" effect of the water vapor is more effective by far in summer than in winter. Were it not for this blanket of water vapor in summer, it is obvious that our days would be much more unbearable so far as temperature is concerned and the nights very cool. Similarly the smaller amount of water vapor in winter tends to reduce the amount of radiation absorbed by the atmosphere, hence making our winters relatively colder on this score than our summers. That is, our solar climate generates a cycle of events which tends to augment its effect in winter by its influence on terrestrial moisture, and on the contrary in summer it tends to retard and conserve its effect by its influence on the same agent. This is probably an important factor in explaining the great contrast existing in winter between polar and equatorial regions and hence the stronger gradients and more intensive circulation than in summer.

VII. SUMMARY

Tables have been introduced (2, 3, 7) for computing the average absolute humidities at various heights, and the total vapor content of m². columns extending from the ground to various heights above sea level, from the mean vapor pressures at the surface, for eight stations in the United States east of the Rocky Mountains.

An equation, 25, has been given to permit the use of the data given in tables 3 and 7 for other stations not too distantly located from those given and physiographically similar. The errors resulting from the methods employed have been fully discussed. It is emphasized that serious errors may result if the given factors are used to compute the required vapor contents for periods of less than a season.

Under the discussion of errors, a number of topics of more general interest have been treated. Among these may be mentioned: The vapor distribution in inversions and the mechanism involved (V, 2, a.); the diurnal variation of absolute humidity near the surface, near mountains, and in the free air (V, 2, b.); errors due to the use of hair hygrometers at low temperatures (V, 2, e.); errors in vapor pressures computed from hair hygrometer readings at temperatures below 0° C. (V, 2, f.)

The various data, viz. f_h, $\overline{W_h}$, F^h_s and $\overline{S^h_s}$ (see definitions in Sec. II), have been discussed with regard to their seasonal and geographical variations. Special emphasis has been laid on the air trajectories and solar radiation to explain some of the differences found.

A study of the relationship between average precipitation, atmospheric water vapor content, and other factors has been begun. It may be stated at this time that the mean precipitation is not directly proportionate to the mean vapor content but depends to quite an extent upon other factors also. It is hoped to publish a paper on this subject in the future.

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SOLAR RADIATION AS A METEOROLOGICAL FACTOR[1]

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SYNOPSIS

Variations in the earth's solar distance cause variations in the intensity of solar radiation at the outer limit of the earth's atmosphere of very nearly 3.5 per cent on each side of the mean, with the maximum early in January and the minimum early in July.

Variations in solar declination cause seasonal variations in the daily totals of solar radiation as measured at the surface of the earth, which are small at the Equator, but increase rapidly with latitude. At Habana, Cuba, latitude 23° 09′ N., the average daily amount at the time of the summer solstice is about double that at the time of the winter solstice; at Washington, D. C., latitude 38° 56′ N., the corresponding ratio is about 3.5; at Stockholm, Sweden, latitude 59° 21′ N., it is about 20, and at Sloutzk, Union of Socialist Soviet Republics, about 40.

Following explosive volcanic eruptions the great quantity of dust thrown into the atmosphere, some of it to great heights, has diminished the intensity of the direct rays of the sun as received at the earth's surface from 15 to 25 per cent for periods of several months. Such explosions, with their accompanying dust clouds, occurred in 1883, 1888–1891, 1902, and 1912, and a slight cooling of the earth as a whole seems to have followed. On the other hand, there have been no such eruptions since 1912, or during a period of nearly 20 years, and Ångström is of the opinion that on account of the small amount of dust now present in the stratosphere the temperature of the earth should be slightly higher than usual.

For solar constant values it has been claimed that periodicities of from 68 to 8 months exist, with amplitudes of from 0.005 to 0.014 calories, or about 0.3 to 0.7 per cent of the mean value. Also, that there are short-period trends in values, with an average length of five days and an average amplitude of 0.8 per cent. To these short-period trends of less than 1 per cent in magnitude, have been attributed the "Major changes in weather."

A careful study of these various variations in the intensity of solar radiation leads to the conclusion that weather changes are brought about, not by short-period trends of less than 1 per cent, but by the manyfold difference in the intensity of the solar radiation received by the earth in equatorial and polar regions. As a result great temperature differences exist between these regions. Gravity causes the heavy cold air to displace the lighter warm air at the surface, and a polar-equatorial circulation is set up, turbulent in character, especially in winter when the temperature difference is most marked. Well-defined movements of this character are to be found on the weather maps of the different countries, and examples are shown in this paper in reproductions of weather maps for the United States. It is to studies of this turbulent polar-equator movement of air that meteorologists look for improvements in weather forecasting, and it is for such studies that the meteorological work of the Jubilee International Polar Year 1932–33 is now being organized.

INTRODUCTION

Although in this paper solar radiation is to be considered from the standpoint of the meteorologist, there are certain astrophysical and astronomical facts that also must be kept in mind.

Thus, astrophysical research has shown that the sun is a hot, luminous body, perhaps gaseous throughout, with its outer layers rotating about the solar axis at different rates in different latitudes. The quality of solar radiation is about that of a black body at a temperature of 6,000° A. This may therefore be taken as the effective temperature of the sun. The temperature of its center, on account of the enormously high pressure that must there prevail, is variously estimated to be from thirty to sixty million degrees.

The sun radiates, we are told, 3.79×10^{33} ergs of energy per second, corresponding to a loss of about 4,000,000 tons of mass per second. Of this vast amount of energy the planets and their satellites intercept about 1/120,000,000, and the earth about 1/2,000,000,000, or 4.1×10^{16} gram-calories per second.

What becomes of all the solar radiant energy except that intercepted by the planets and their satellites, and how the sun maintains this enormous output of energy without apparent impairment of its resources, while interesting problems, will not be considered here. Rather, we shall confine our attention to the one 2-billionth part that is intercepted by the earth, and which is of vital interest not only because it is the source and the support of all life on the earth, but also because it is the source of weather and climate.

ANNUAL VARIATIONS IN SOLAR RADIATION INTENSITY RECEIVED BY THE EARTH

The earth is at its mean solar distance of approximately 93,000,000 miles twice each year—in 1931 on April 4 and October 5. It was nearest to the sun on January 3, and farthest from it on July 6. The ratio of the longest to the shortest distance is 1.034, and since the radiation intensity varies inversely as the square of the distance from the radiating body, other things being equal its intensity early in January should have been nearly 7 per cent higher than in early July. Therefore solar radiation received by the earth has an annual variation in intensity of about 7 per cent, and we in the Northern Hemisphere are now favored by the fact that the maximum intensity occurs during our winter.

Besides the annual variation in the earth's solar distance there is also the annual variation in the sun's apparent declination due to the inclination of the earth's axis of rotation to the plane of the ecliptic, in consequence of which the position of the sun in the heavens coincides with the plane of the terrestrial equator at the time of the equinoxes only. From March 21 to September 21 the sun is north of the terrestrial equator, or its declination is north, and during the remainder of the year it is south. During the summer months, therefore, the sun's rays strike the surface of the earth in the Northern Hemisphere at a smaller angle from the vertical, and thus have a shorter path through the atmosphere during most of the day than during the winter months; also,

[1] Presented before Section B, A. A. A. S., at a joint session with the American Meteorological Society at New Orleans, La., on December 30, 1931.

the sun is above the horizon a greater number of hours. The reverse, of course, is the case in the Southern Hemisphere, which has its winter while the Northern Hemisphere has its summer.

Thus, from variations in the solar declination there results a second annual variation in the vertical component of solar radiation intensity, which variation itself varies in amount with latitude. In consequence, for the average daily totals of solar radiation as received on a horizontal surface the annual variation is slight at the Equator, at Habana, Cuba, the midsummer totals are about double those for midwinter, at Washington, D. C., they are 3.5 times as great, and at Stockholm, Sweden, and Sloutzk, Union of Socialist Soviet Republics, the ratios are 20 and 40, respectively.

ATMOSPHERIC DEPLETION OF SOLAR RADIATION

Besides the annual variation in solar radiation intensity due to the earth's position in its orbit, and that due to solar declination, there are irregular variations owing to changes in the constituents of the atmosphere. In general, these constituents may be divided into three classes, as follows:

(1) Atmospheric gases; (2) solid particles, principally dust; and (3) condensed gases, principally water.

The constituents of the atmosphere deplete the solar radiation that passes through it in three ways, as follows:

(*a*) Scattering by atmospheric gas molecules, the law of which has been developed in a workable form by Raleigh and King.

(*b*) Absorption by atmospheric gases, the laws for which have been determined by Fowle and others, so that the depletion may be computed provided we know the atmospheric content of each of the absorbing gases, of which the principal are water vapor, ozone, and carbon dioxide.

(*c*) Scattering by solid particles and condensed gases. Ångström has developed the law for scattering by dust

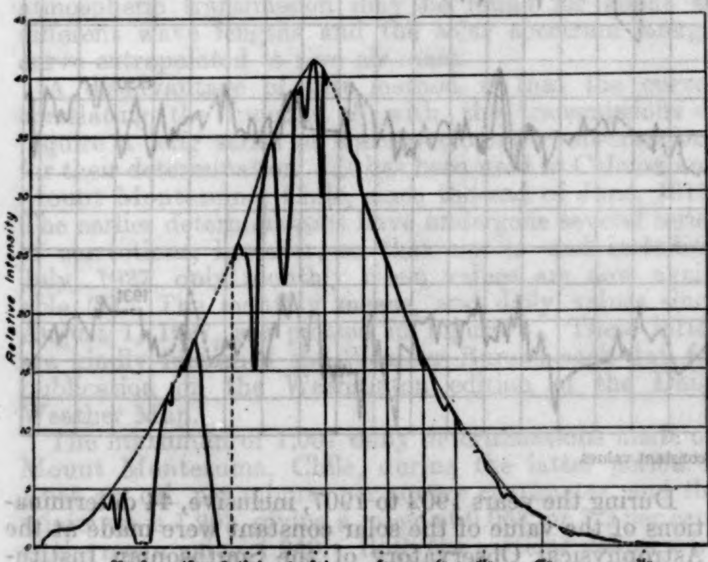

FIGURE 1.—Bologram of solar radiation

particles, provided their diameters are known, and has put it in a convenient form for computing. Unfortunately, atmospheric dust particles vary in size. Those due to explosive volcanic eruptions, and also dust particles from city smoke, average much larger in diameter than ordinary atmospheric dust, for which Ångström's law has been developed.

The extent of the depletion of radiation both by scattering and by absorption varies with the wave length. Therefore, for its determination spectro-bolometric measurements are necessary.

Figure 1 is a spectro-bologram of solar radiation obtained by the Astrophysical Observatory of the Smith-

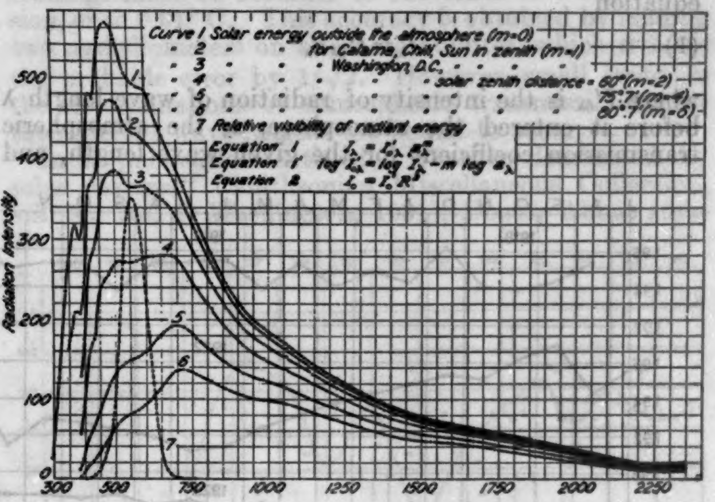

FIGURE 2.—Normal solar radiation energy curves

sonian Institution by means of a 60° ultra-violet crown-glass prism (1). Note the depressions in the curve caused by absorption of energy in the water-vapor bands. In one of these the position of the zero line of the curve has been redetermined. Note also that the wave-length scale is more open at the short-wave or ultra-violet end of the bologram than at the infra-red end. In Figure 2 the wave-length scale has been made uniform throughout and is reversed in direction from that in Figure 1, so that wave lengths here increase from left to right. In addition to the fact that the water vapor absorption bands are not here shown, the energy distribution with respect to wave length has been materially changed, so that for curve 1, "Solar energy outside the atmosphere" (2), the maximum intensity is in the blue. In curve 2 (3), for radiation intensities measured at Calama, Chile, and for curves 3 to 6, inclusive, for intensities measured at Washington, D. C. (4), with the sun at increasing angular distances from the zenith, the maximum of the energy curves is shifted successively from the blue through the green, yellow, and orange to the red, which indicates why, as the sun approaches the horizon, it often assumes a reddish hue.

However, the apparent color of the sun can not be determined from the wave length of the maximum of the spectrum energy curve alone. Curve 7, Figure 2, gives the relative visibility of radiant energy of different wave lengths. It has a decided maximum in the green, and from this it has been argued that if we could view the sun from outside the earth's atmosphere its color instead of being blue, as Langley claimed, would be green.

THE DETERMINATION OF THE VALUE OF THE SOLAR CONSTANT OF RADIATION

Spectrobolometric measurements of the intensity of solar radiation throughout the solar spectrum, made at the surface of the earth, form the basis for determinations of the intensity before it entered the earth's atmosphere. The theory of the determination is simple, but the observational work is tedious.

Referring to Figure 2, curves 4, 5, and 6 represent solar spectrum energy curves based on spectrobolograms ob-

tained with the sun at zenith distances 60.0°, 75.7°, and 80.7°. The corresponding length of the paths, m, traversed by the solar rays to reach the surface of the earth, expressed in terms of the length when the sun is in the zenith, are, respectively, 2.0, 4.0, and 6.0. The depletion of solar radiation of different wave lengths is expressed by the equation

$$I_\lambda = I'_{0\lambda} a_\lambda^m \quad (1)$$

where $I'_{0\lambda}$ is the intensity of radiation of wave length λ before it entered the atmosphere, a_λ the atmospheric transmission coefficient for the given wave length, and

Pyrheliometric readings made at the time the bolograms are obtained make it possible to express the radiation intensity they represent in absolute heat units, and the ratio of their areas, after making allowance for band absorptions, to the area of the bologram for zero atmosphere, make possible the determination of the intensity outside the atmosphere, I'_0, with considerable accuracy. Then for the solar constant

$$I_0 = I'_0 R^2, \quad (2)$$

where R is the earth's radius vector at the time the measurements were made, in terms of its mean value.

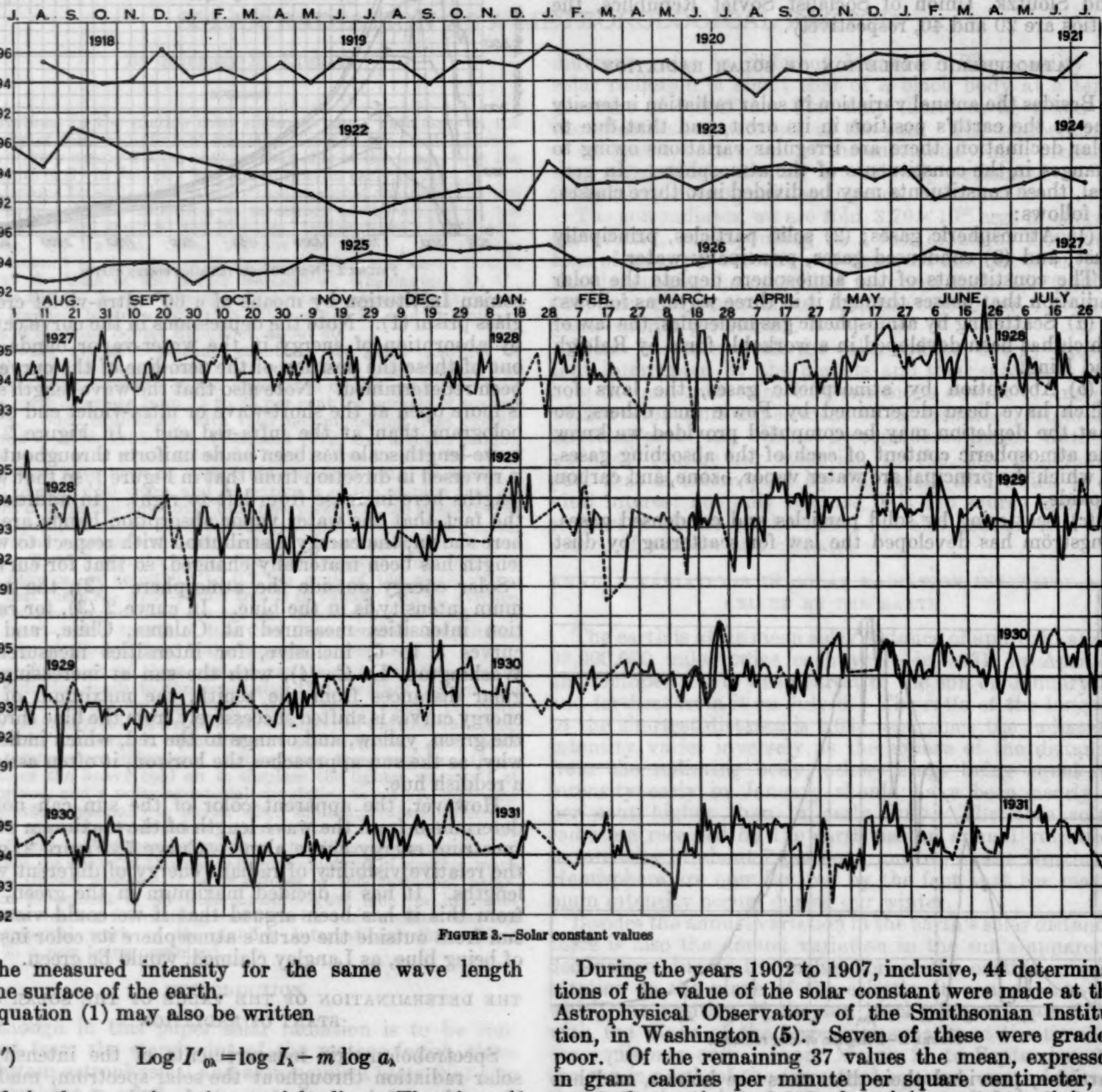

FIGURE 3.—Solar constant values

I_λ the measured intensity for the same wave length at the surface of the earth.

Equation (1) may also be written

$$\text{Log } I'_{0\lambda} = \log I_\lambda - m \log a_\lambda \quad (1')$$

which is the equation of a straight line. Therefore, if the atmospheric transmission remains constant throughout a half-day period, from several bolometric records it will be possible to extrapolate values of I_λ to zero atmosphere, and thus to construct the spectrobologram for solar radiation outside the atmosphere.

During the years 1902 to 1907, inclusive, 44 determinations of the value of the solar constant were made at the Astrophysical Observatory of the Smithsonian Institution, in Washington (5). Seven of these were graded poor. Of the remaining 37 values the mean, expressed in gram calories per minute per square centimeter, is 1.968, the maximum 2.252, the minimum 1.814, giving a range of 0.438, or 22 per cent of the mean value. There seemed to be such strong evidence of marked changes in the value of the solar constant that the Smithsonian Institution established an observing station on Mount Wilson, Calif., where solar constant determinations were

made during the summer and fall months from 1905 to 1920, the year 1907 excepted, and at Bassour, Algeria, in 1911 and 1912. A few determinations were also made on Mount Whitney in 1909 and 1910, and at Hump Mountain in North Carolina in 1917–18. The mean of all values obtained to the end of 1920, those at Hump Mountain excepted, is 1.936 gram calories per minute per square centimeter, and the range is from 2.133 to 1.780, or 18 per cent (6).

Still impressed by the marked variations in the value of the solar constant, in July, 1918, the Smithsonian Institution established an observing station at Calama, Chile, where it was hoped that solar constant values could be determined throughout the year instead of during the summer and fall months only, as was the case at Mount Wilson. During the first year the fundamental method followed at Mount Wilson was employed. Considerable variations in the solar constant were found, the maximum value being 2.018, the minimum 1.865, giving a variation of about 8 per cent of the mean (7).

It was recognized by the Smithsonian Institution that it is a weakness of the spectrobolometric method of determining the value of the solar constant that it is necessary to assume that the atmospheric transmission does not change during the few hours in the morning or the afternoon required to obtain bolograms over a sufficient range of air mass values to permit of accurate extrapolation to zero atmosphere. This led to the development of a new method of determination (8), which is independent of changing atmospheric transmissibility, and which therefore enables determinations to be made on days when a clear sky early in the half-day period becomes bad later, or vice versa, as well as on continuously clear days.

Briefly, from a measurement of the brightness of the sky in a 15° zone about the sun, and a spectrobolometric determination of the absorption of solar radiation by water vapor and other gases of the atmosphere, a so-called function, *F*, is obtained, by means of which, in connection with empirically determined curves, the atmospheric transmission may be found for about 40 different wave lengths and the solar spectrum energy curve extrapolated to zero air mass.

A disadvantage of this method is that the curves correlating the function *F* with the transmissions a_λ require a long series of spectrobolometric observations for their determination. It has been used at Calama and Mount Montezuma, Chile, since the end of June, 1919. The earlier determinations have undergone several series of corrections, however, so that up to and including July, 1927, only monthly mean values are now available (9). The monthly means, and daily values since August 1, 1927, are plotted in Figure 3. These latter are kindly furnished the Weather Bureau each day for publication on the Washington edition of the Daily Weather Map.

The maximum of 1,007 daily determinations made on Mount Montezuma, Chile, during the latter period is 1.966 gr. cal. per minute per square centimeter, and the minimum is 1.903, giving a range of 0.063, or 3.2 per cent of the mean value, 1.940. Both the extreme values were rated *S*− by the observer, signifying that the sky conditions at the time were not the best. These 1,007 determinations give a standard deviation of ±0.00856. There is evidence of periodic variations, however, and if we confine our attention to 157 determinations made between November 12, 1929, and June 26, 1930, in which there is little evidence of such variation, the standard deviation is ±0.00536 and the probable error a little less than ±0.2 per cent. This is an exceedingly small error.

Recalling that the absolute value of the determination rests on the rate of change in temperature of the Smithsonian silver disk pyrheliometer when exposed to solar radiation, that the rate is only about 4° C. in 100 seconds, and is measured by a mercurial thermometer graduated on the stem to tenths of a degree, it is evident that these readings must be accurate to the tenth of a scale division, or to 0.01° C. This accuracy is obtained by reading two pyrheliometers on alternate minutes, which reduces the probable error by $1/\sqrt{2}$. However, small errors in the determinations of atmospheric transmissibility for the different wave lengths are bound to occur.

In a publication entitled "Weather dominated by solar changes" (Smithsonian Miscellaneous Collection, vol. 85, No. 1, Washington, 1931), Doctor Abbot sum-

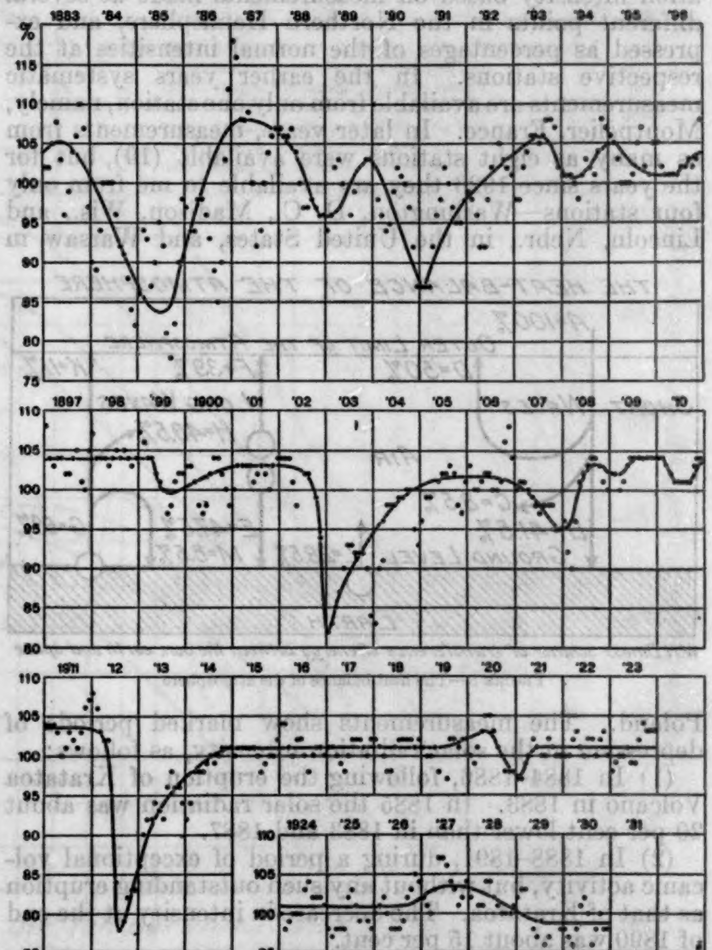

FIGURE 4.—Monthly averages of solar radiation intensity measured at the surface of the earth, expressed as percentages of the monthly normals

marizes the results of his studies of periodicities in solar constant values, basing his conclusions principally on the values obtained in the years 1924 to 1930, inclusive. He finds periodicities of 68, 45, 25, 11, and 8 months, respectively, in length, with amplitudes of from 0.3 to 0.7 per cent of the mean value, and projects them into the future to predict the trend of solar constant values to the end of 1932. The values actually obtained in 1931 are considerably lower, and have less range than was predicted.

In this publication Abbot states "I shall present evidence to show that weather * * * is caused chiefly by the frequent intervals of actual change in the emission of radiation within the sun itself." Then after discussing sequences of rising and falling solar radiation intensity, which he finds to occur in short intervals,

averaging five days, and in amount exceeding 0.4 per cent, and averaging 0.8 per cent of the value of the solar constant, he makes the further statement that "Major changes in weather are due to short-period changes in the sun." The reasoning by which this conclusion was reached is somewhat involved, and those interested are referred to the original paper for its elucidation.

Studies by forecasters and others at the United States Weather Bureau do not confirm the contention that "Major changes in weather are due to short-period changes in the sun."

VARIATIONS IN THE MEASURED INTENSITY OF SOLAR RADIATION RECEIVED AT THE SURFACE OF THE EARTH

In Figure 4 are shown monthly averages of solar radiation intensity based on measurements made at several different points in the Northern Hemisphere, and expressed as percentages of the normal intensities at the respective stations. In the earlier years systematic measurements are available from only one station, namely, Montpelier, France. In later years, measurements from as many as eight stations were available (**10**), but for the years since 1923 they are available to me from only four stations—Washington, D. C., Madison, Wis., and Lincoln, Nebr., in the United States, and Warsaw in Poland. The measurements show marked periods of depression in the solar radiation intensity, as follows:

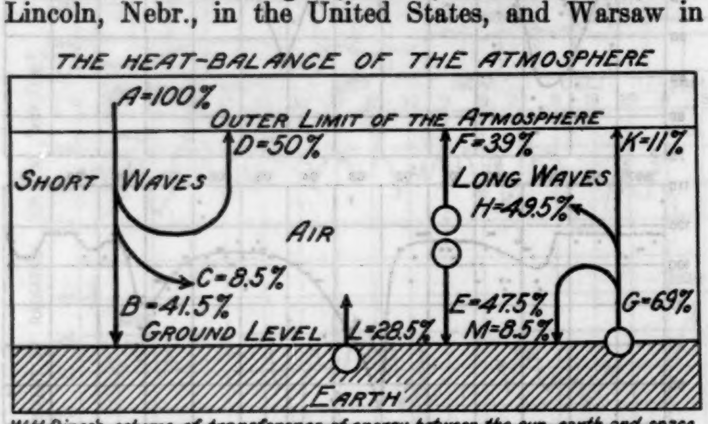

FIGURE 5.—The heat balance of the atmosphere

(1) In 1884–1886, following the eruption of Kratatoa Volcano in 1883. In 1885 the solar radiation was about 20 per cent lower than in 1883 and 1887.

(2) In 1888–1891, during a period of exceptional volcanic activity, but without any such outstanding eruption as that of Kratatoa. The decrease in intensity at the end of 1890 was about 15 per cent.

(3) In 1902–3, following the eruption of Pelée, Santa Maria, and Colima in 1902, with a sharp depression in solar radiation intensity at the end of 1902 of 20 per cent.

(4) In 1912–13, following the eruption of Katmai Volcano in June, 1912, which caused a decrease in solar radiation intensity in the following month of nearly 25 per cent.

The researches of Abbot (**11**), Humphreys (**12**) and others, indicate that these and earlier volcanic eruptions have been followed by a slight fall in the temperature of the earth as a whole, and especially at continental stations.

On the other hand, Ångström in a recent "Notiser" calls attention to the fact that since 1912, or for nearly 20 years, there have been no marked volcanic eruptions of an explosive character, such as throw great quantities of dust into the atmosphere. Therefore, the upper atmospheric layers, or the stratosphere, must now be unusually clear, and, in consequence, should deplete the incoming solar radiation less than usual. As a result the earth as a whole should experience a slight rise in temperature. This seems to be true of North America, while Europe has been cold and wet. Such apparent anomalies are not unusual, however, and are attributable to modifications in the atmospheric circulation.

It should be stated that of the radiation scattered from the direct rays of the sun by dust, perhaps one-half eventually finds its way to the earth's surface as diffuse radiation.

THE HEAT BALANCE OF THE ATMOSPHERE

In Volume III of his Manual of Meteorology, page 106, Figure 50, Sir Napier Shaw reproduces "W. H. Dine's (**13**) scheme of transfer of energy between the sun, the earth, and space," which is here shown in Figure 5.

	Per cent
(1) Short-wave, or solar radiation:	
A=solar radiation received at the outer limit of the atmosphere, $=1.94\times 1440\times \frac{\pi R^2}{4\pi R^2}=700$ gram calories per square centimeter per day	=100
D=amount returned to space by scattering and reflection	= 50
C=amount absorbed by the gases of the atmosphere	= 8.5
B=amount expended at the surface of the earth	= 41.5
$D+C+B$=total short-wave radiation accounted for	=100.0
(2) Long-wave, or low-temperature radiation:	
E=amount radiated to the earth by the atmosphere	= 47.5
M=amount scattered and reflected to the earth by the atmosphere	= 8.5
$[B]+E+M$=total radiation reaching the earth's surface	= 97.5
G=amount radiated from the earth's surface	= 69.0
L=amount transferred from earth to atmosphere through conduction and evaporation	= 28.5
$G+L$=total transmitted from earth to atmosphere	= 97.5
F=amount radiated from the atmosphere to space	= 39.0
K=amount transmitted through the atmosphere to space	= 11.0
$[D]+F+K$=total from atmosphere to space	=100.0
It is significant that of the total radiation reaching the surface of the earth $(B+E+M)$, B, short-wave radiation	= 41.5
And $E+M$, long-wave radiation	= 56.0
Also, of the total radiation expended in the atmosphere, $(C+L+H)$, C=short-wave radiation	= 8.5
And $L+H$, long-wave radiation	= 78.0

When we consider the secondary part played by the short-wave radiation in heating the atmosphere, and the many factors that enter into the determination of the relative values of D, C, and B, such as cloudiness, character of the ground cover (for example, dark or light colored soil, vegetation, sand, or snow), the water-vapor content and dust content of the atmosphere, etc., we may well question how a variation of less than 1 per cent in the value of A in a period of four to five days can have sufficient effect upon the value of either $M+E+B$ or upon $L+H+C$ to become apparent in the air temperature at a given place.

DAILY TOTALS OF SOLAR RADIATION RECEIVED AT THE SURFACE OF THE EARTH

In Figure 6, curve 1 shows for the entire year the daily totals of solar radiation received at the outer limit of the atmosphere for the latitude of Washington, 38° 56′ N. Broken lines show what would have been the daily totals in midsummer and in midwinter, had the earth been at its mean solar distance. Curve 2 gives the daily totals with clear skies measured at Twin Falls, Idaho, latitude

42° 29′ N., altitude about 4,300 feet, and curve 3 gives corresponding values for Washington, D. C., altitude about 400 feet.

Curve 4 gives the normal daily values with average skies at Twin Falls, curve 5 the corresponding values for Washington, and curve 6 summarizes measurements made by the weather bureau at the University of Chicago, latitude 41° 47′ N., altitude 688 feet.

On the normal values of curve 5 are superposed the weekly averages for Washington for the year 1925. These values show for the weeks centering on March 22 and 29 a variation at Washington from 111 to 56 per cent of the normal values, or 30 per cent of the amount

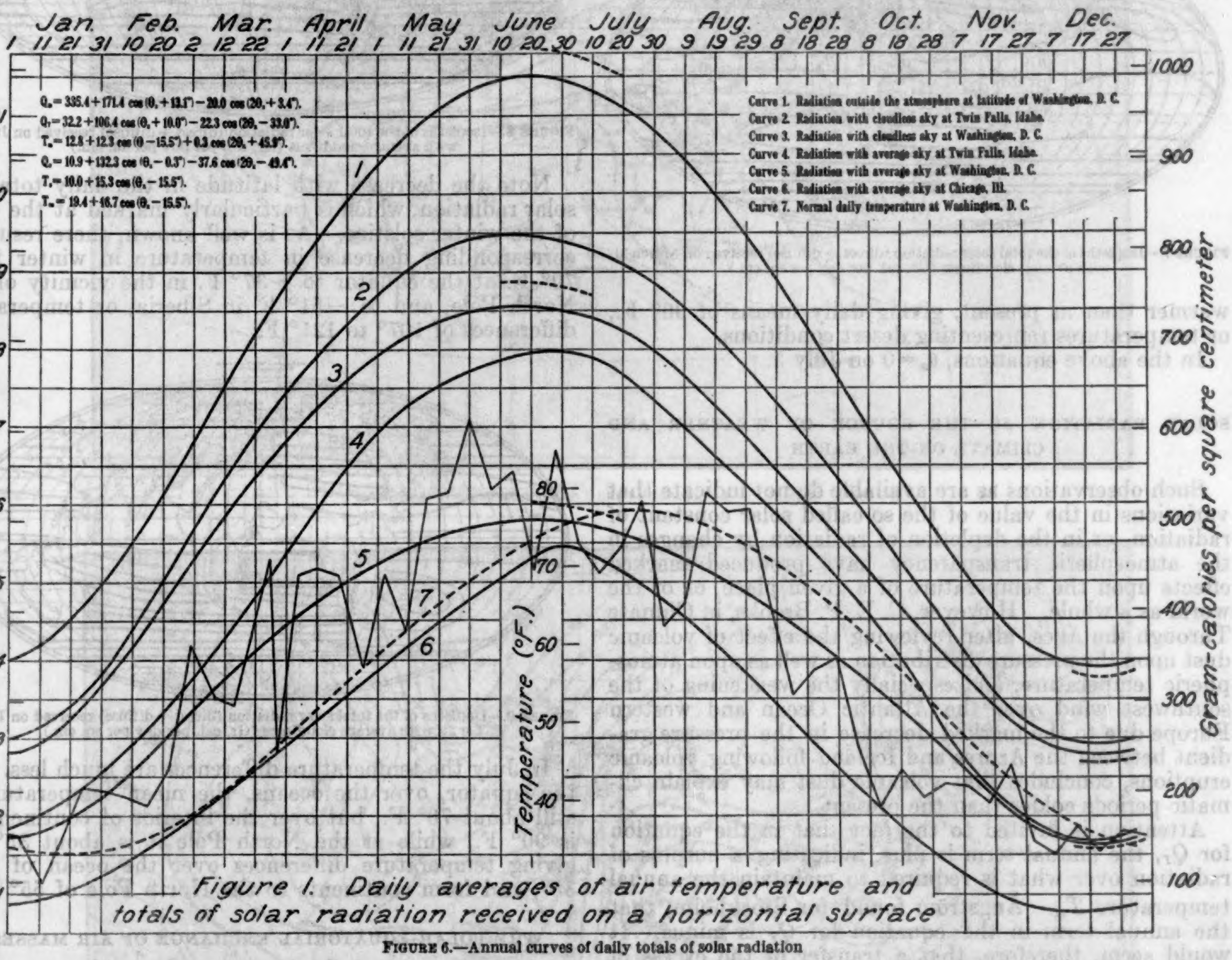

FIGURE 6.—Annual curves of daily totals of solar radiation

received at the outer limit of the atmosphere. Daily values show on September 3 to 4, 1931, at Washington, a variation from 35 to 115 per cent of the normal value, or 41 per cent of the receipt at the outer limit of the atmosphere.

These daily and weekly variations in the total solar radiation received at the surface of the earth are due principally to the amount of clouds present in the atmosphere. Since extensive cloud areas usually accompany storms, considerable portions of a continent may at a given time be covered by clouds.

SOLAR ENERGY RECEIVED PER SQUARE MILE

It is interesting to note that on a cloudless day in midsummer at Twin Falls the daily receipt of solar energy per square mile of surface is equal to nearly 33,000,000 horsepower-hours, and at Washington to nearly 30,000,000. Also, on an average day in midsummer at Twin Falls the daily total is equal to about 27,000,000, and at Washington to 20,000,000 horsepower-hours. If it were possible to concentrate this energy as water power is concentrated, industry would have at its command an inexhaustible source of power.

RELATION BETWEEN INSOLATION AND AIR TEMPERATURE

The annual curves of daily totals of solar radiation and air temperature may be expressed by equations of the Fourier type (**14**). Thus, the equation for Q_m, Figure 6, represents curve 5, and that for T_m represents curve 7 (**15**). Also, we may compute the equation for Q_t the radiation available for heating the atmosphere after deducting from Q_m the loss due to reflection, the amount expended in evaporation, and the amount radiated to space. We may also compute Q_s, the radiation that should be available for heating the atmosphere if the ground were continuously covered with snow from December 1 to February 28, inclusive, and the resulting temperature curve represented by T_s. Likewise, from the equation for curve 3 we may compute the radiation and temperature curves Q_{oc} and T_{oc} for continuous sunshine at Washington.

The equation for T_s shows that with a continuous snow cover on the ground at Washington during the three winter months the midwinter temperatures would be 5° C.

colder than with an average snow cover, due to the greater loss of radiation through reflection, which accords with observations. With no snow on the ground zero temperature Fahrenheit has never been recorded at Washington, while with a snow cover a temperature of $-15°$ F. has been recorded.

Similarly, with continuous sunshine the equation for T_{oe} gives midsummer temperatures 11° C. or 20° F.,

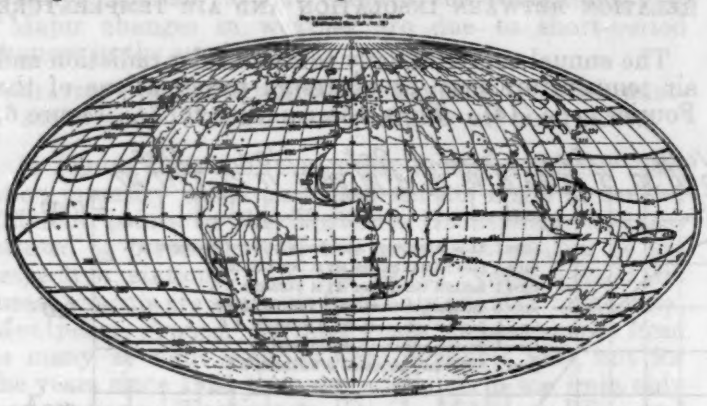

FIGURE 7.—Isopleths of the total solar radiation (direct + diffuse) received on March 21, with average cloudiness (Gr. cal. per day per sq. cm.)

warmer than at present, giving daily means of 96° F., or temperatures representing desert conditions.

In the above equations, $\theta_z=0$ on July 5.

SOLAR RADIATION AS THE SOURCE OF WEATHER AND CLIMATE ON THE EARTH

Such observations as are available do not indicate that variations in the value of the so-called solar constant of radiation, or in the depletion of radiation by changes in the atmospheric transparency have produced marked effects upon the temperature of a given place, or of the world as a whole. However, C. E. P. Brooks, in Climate Through the Ages, after reviewing the effect of volcanic dust upon the pressure distribution as well as upon atmospheric temperature, and especially the weakening of the southwest wind over the Atlantic Ocean and western Europe due to the marked decrease in the pressure gradient between the Azores and Iceland following volcanic eruptions, concludes that volcanic dust may explain climatic periods colder than the present.

Attention is invited to the fact that in the equation for Q_T, the annual term is plus, indicating a surplus of radiation over what is required to maintain the annual temperature T_m. Ångström found for Stockholm, that the annual term in the equation for Q_T is minus. It would seem, therefore, that a transfer of the excess of heat in low latitudes is necessary to make up the deficit in high latitudes.

It is difficult to chart daily average values of insolation over the continents for the reason that altitude above sea level is an important factor in determining these values. Only a few radiation measurements have been made at sea, but if we know the average cloudiness, the average water-vapor content and dust content of the atmosphere over the ocean, we may compute the corresponding average solar radiation intensity for a given day at given latitudes with reasonable accuracy. This I have done, using such records of cloudiness, air temperature, and relative humidity for marine stations as are available (16). The results for average cloudy conditions are shown in Figure 7 at the time of the vernal equinox, in Figure 8, at the time of the summer solstice, and in Figure 9 at the time of the winter solstice. They check satisfactorily with such measurements as have been made.

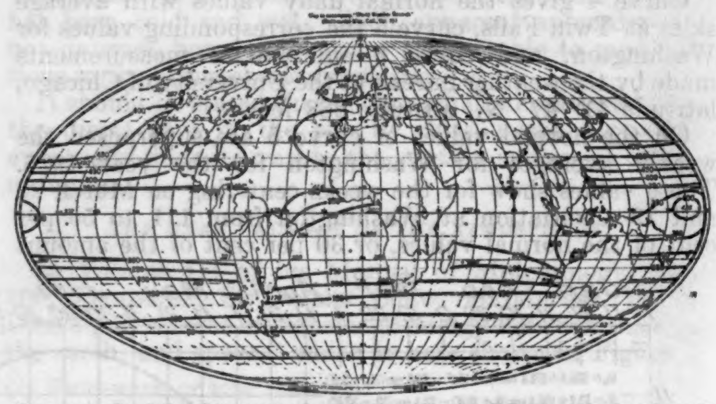

FIGURE 8.—Isopleths of the total solar radiation (direct + diffuse) received on June 21, with average cloudiness (Gr. cal. per day per su. cm.)

Note the decrease with latitude in the daily totals of solar radiation, which is particularly marked at the time of the winter solstice. As is well known, there results a corresponding decrease in temperature in winter from 70° F. at the equator to $-37°$ F. in the vicinity of the North Pole, and to $-51°$ F. in Siberia, or temperature differences of 107° to 121° F.

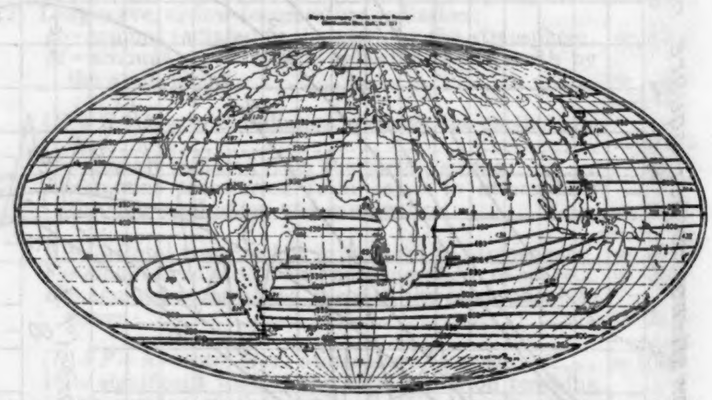

FIGURE 9.—Isopleths of the total solar radiation (direct + diffuse) received on December 21, with average cloudiness (Gr. cal. per day per sq. cm.)

In July the temperature differences are much less. At the equator, over the oceans, the mean temperature is still about 70° F., but over the interior of continents it is 90° F., while at the North Pole it is about 35° F., giving temperature differences over the ocean of only 35°, and from continents to the North Pole of 55° F.

THE POLAR-EQUATORIAL EXCHANGE OF AIR MASSES

When two bodies of air of unequal temperatures lie near each other, gravity causes the cold air to displace the warm air at the earth's surface. In this way atmospheric circulation is initiated, which on a nonrotating globe of uniform surface, might be quite regular. On a rotating globe with an irregular surface like the earth, consisting partly of land and partly of water, and the land surfaces not planes, but mountain peaks and mountain chains separated by deep valleys, the circulation of the air is bound to be turbulent. It is this turbulent interchange of air between the warm and the cold regions on the earth's surface that generates storms and the various phases of weather that accompany them.

Figures 10, 11, 12, and 13 give an illustration of these air movements over the United States and the accompanying weather changes. On the morning of January

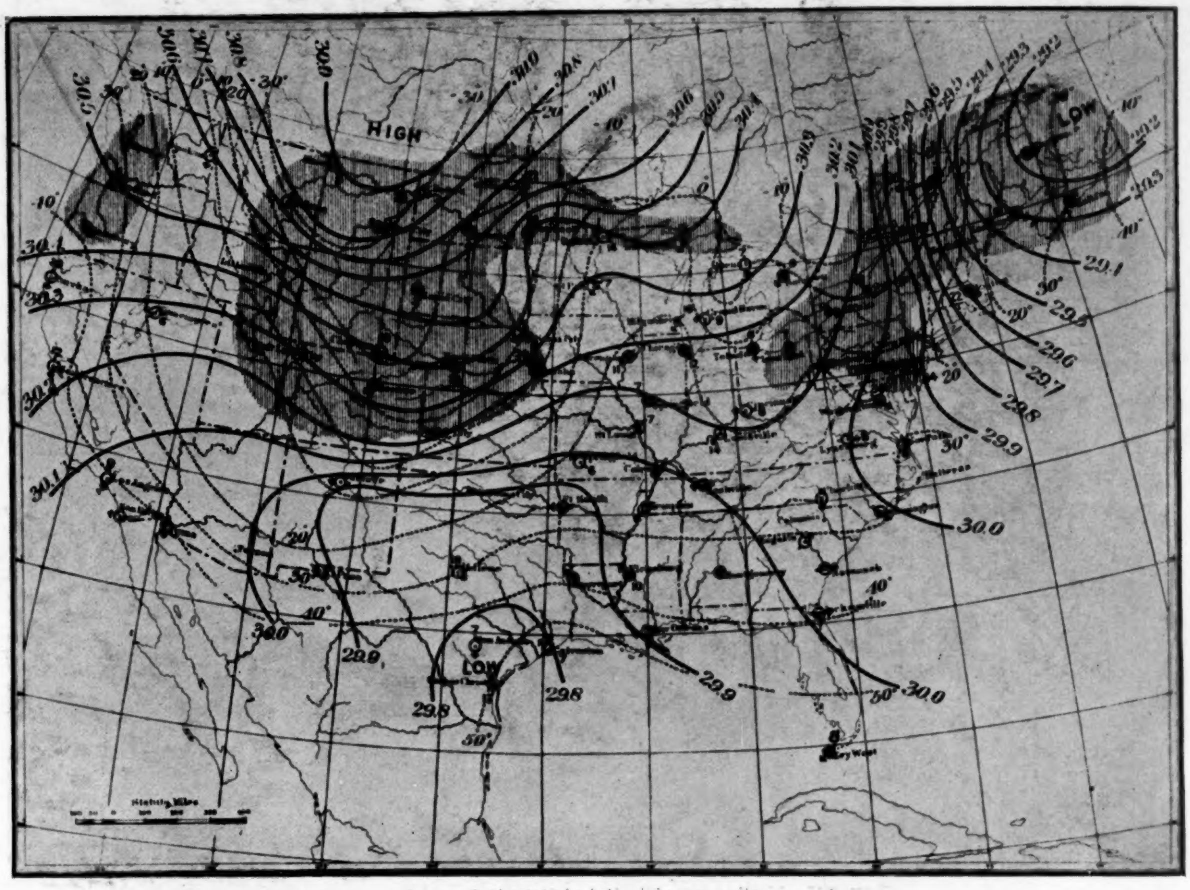

FIGURE 10.—Weather map of the United States for 7 a. m., January 7, 1886

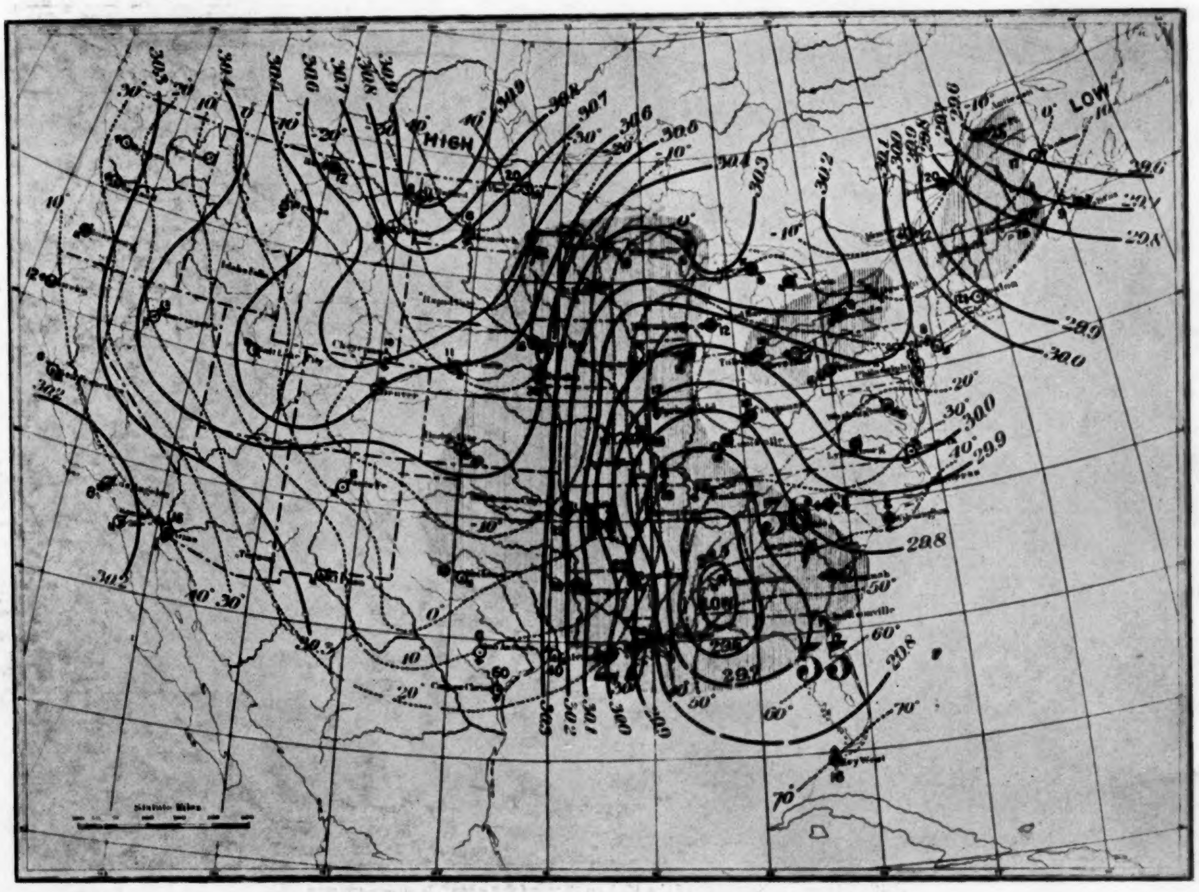

FIGURE 11.—Weather map of the United States for 7 a. m., January 8, 1886

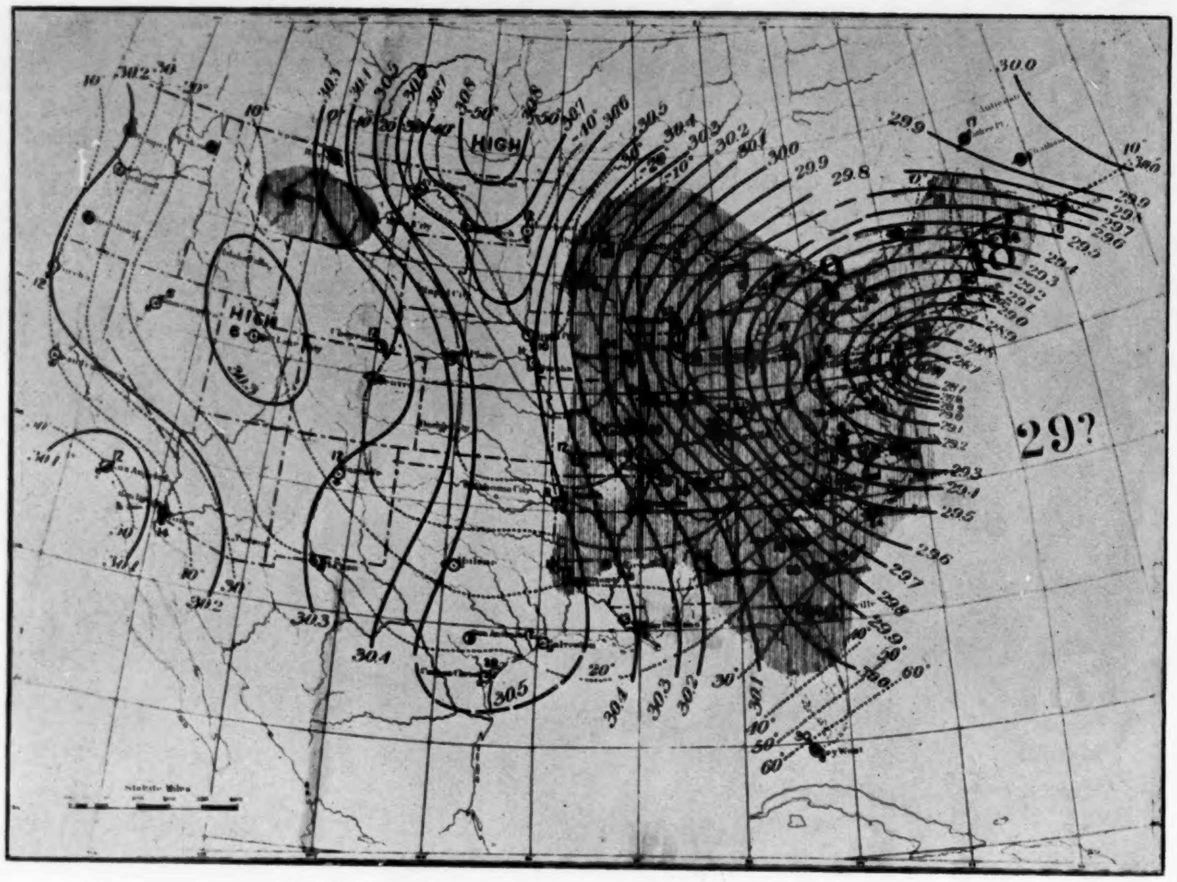

FIGURE 12.—Weather map of the United States for 7 a. m., January 9, 1886

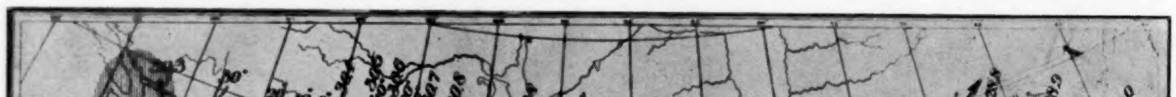

FIGURE 13.—Weather map of the United States for 7 a. m., January 10, 1886

7, 1886, a low-pressure area was passing off the North American coast near the mouth of the St. Lawrence River. Warm south to southwest winds prevailed on its front, and cold winds, generally from the northwest, on its rear. A high-pressure area was overspreading the Rocky Mountain Plateau with winds generally from the north and with temperatures as low as 30° below zero. There were indications that a cyclone was developing on the Texas coast, with winds in the lower Mississippi valley from the southeast.

In the July, 1931, number of the MONTHLY WEATHER REVIEW, Bjorkdal (17) defines *frontal zones* and *fronts*, as follows:

When two air masses each uniformly homogeneous approach each other nearer than about 1,000 kilometers (620 miles), the area between them no longer fulfills the conditions of a homogeneous air mass. A *frontal zone* occurs which can gradually sharpen to a *front*. Fronts are narrow inclined transition zones of the same vertical extent as the air masses. It is essential that the difference of the values on both sides of the front of at least one of the independent elements (temperature, pressure, wind, humidity) is so great that it has an appreciable effect on the great-scale dynamics (of the air mass).

Evidently on the morning of January 7, a *frontal zone* extended from the Texas coast northeastward to Illinois, as shown by the wind directions and temperature lines. On the morning of the 8th, it had sharpened into a *front* which extended northward from near the mouth of the Mississippi to Lake Michigan having a 20° rise in temperature in 24 hours with the south winds to the east and a 30° fall in temperature with the north winds to the west. Large figures show the average temperature in each quadrant of the cyclone.

Note on the 9th the marked development of the low center on this polar front, and its movement toward the northeast. The flow of cold air from the north now covers practically the whole country east of the Rockies, except the extreme northeastern section. The map for January 10 shows temperatures as low in Florida as in New Brunswick, Canada, near the mouth of the St. Lawrence River.

Cyclonic storms of this type often persist for days, crossing oceans from continent to continent, and in rare cases completing the circuit of the globe.

The above are only instances of great major changes which are continually going on in weather conditions all over the earth; although during the spring months, as the temperature difference between the equator and the pole diminishes, the extent and the intensity of the air movements also diminish, and become comparatively weak in summer, just when the effect of solar variability should be at its maximum. Therefore, is it rational to believe that these major weather changes are caused and explained by alleged short-period changes of less than 1 per cent in the intensity of solar radiation? A part if not all of this 1 per cent variation must be set off as caused by inevitable accidental errors, but even if the whole of it were real solar change, can we believe that if this small variation were to cease our major weather changes would disappear also?

The importance attributed by meteorologists to the polar-equatorial exchange of air is attested by the program adopted by the International Meteorological Committee for the Jubilee Polar Year, 1932-33. It is proposed to surround the North Pole with stations so completely equipped and manned that it will be possible to publish hourly values of the principal meteorological elements. It is also proposed to reproduce all automatic records obtained. Those from polar stations should show the origin of polar fronts, and those from stations in lower latitudes, their progress. Meteorological observations will not be confined to low-level stations, but upper air conditions will be recorded, at mountain stations, and by means of balloons, kites, and airplanes at numerous aerological stations. Also, especial attention is to be given to observations of the aurora, by eye observations, by synchronous photographs at neighboring stations to determine auroral heights, and by spectroscopic observations, with a view to learning more about atmospheric conditions at great heights.

As stated by the chairman of the commission for the polar year (18).

The further that extensions have been made of the dynamical theories of air interaction in moderate latitudes for practical forecasting purposes, the clearer has it become that atmospheric processes in the polar regions of both hemispheres play a predominant part. These regions are very often the source of the surges in the atmosphere whose necessary outcome are the weather variations at low latitudes. An intimate study, therefore, of the behavior of the atmosphere in high latitudes has now become a necessity for the extension in knowledge of weather processes.

It is from studies of this character that meteorologists are attempting to increase their knowledge of the generation and movements of storms and of the weather changes that accompany them.

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INTERNATIONAL MEETINGS IN SEPTEMBER AND OCTOBER, 1931

By C. F. BROOKS

Three recent international meetings of interest to meteorologists generally were the International Geographical Congress in Paris, the meetings of three commissions of the International Meteorological Organization in Innsbruck, and the joint meeting of the German and Austrian meteorological societies in Vienna. At the Paris congress, local climates and changes of climate in historic times were discussed at some length. The occurrence of marked contrasts in climate, especially temperature, in surprisingly short distances, was emphasized. A study of the different economic effects of contrasted climates in modern times was urged as a basis for interpreting the human record of earlier centuries in terms of climate. Certain changes in Egypt in the past 2,000 years are ascribable to factors other than climate, and it was concluded that the climate of Egypt has not changed appreciably since the time of Christ. This tallies with similar investigations made in Palestine and in Greece.

The meetings in Innsbruck comprised the Climatological, the Terrestrial Magnetism and Atmospheric Electricity and the Polar Year commissions. The city, the university, and the Tirolean government officials were unstinting in their entertainment of the small group of meteorologists assembled for these meetings. There were complimentary dinners and excursions to the mountains near by. The snow and cold weather of the first four days made the last two only the more beautiful.

Though this was the first meeting of the Climatological Commission, Dr. H. von Ficker, the president, guided its labors so effectively and Dr. W. Knoch, the secretary, prepared such excellent minutes, that a large program was put through without haste, yet within the limits of the seven sessions originally scheduled. Chief attention was directed toward bringing climatological programs into step with modern synoptic programs, both as to hours of observation and publication of daily values. Radio broadcasting of monthly means for a selected network of stations over the earth was recommended in order to aid studies in world weather and to make possible some long-range forecasting based on knowledge already gained. Studies in dynamic climatology, particularly of the frequency of occurrence of different air bodies (e. g., polar air and tropical air) and of the frequency of passage of fronts should be made at selected stations. Furthermore, the commission believed that daily weather maps of the northern hemisphere were much to be desired.

The Commission on Terrestrial Magnetism and Atmospheric Electricity and the Polar Year Commission under the able leadership of Dr. P. La Cour greatly advanced the project for the International Polar Year, 1932–33. On account of the world-wide economic depression the question was raised as to whether the plans for the polar year should be pressed forward or deferred until a more auspicious time. Those members of the commission who were present unanimously favored continuing the polar year plan, so great was the current interest, and so hopeful were they that notable results would be obtained. The networks of stations were recommended in detail, their programs were outlined, including photographic observations of the aurora, and detailed cloud and aerological observations. Radiosounding balloon work for certain stations was specially recommended, and the need for mountain observatories stressed. Plans were laid for observations during the total solar eclipse of August 31, 1932. The cooperation of observatories all over the world was solicited, especially on international days.

High spots of the meeting of the Austrian and German meteorological societies in Vienna were, the unveiling of the bronze placque of Julius von Hann in the hallway of the Zentralanstalt für Meteorologie und Geophysik, Dr. P. Goetz's photographs of sun pillars, and the symposium and exhibit on microclimatology arranged by Dr. W. Schmidt. This symposium disclosed a considerable activity in local climatology in central Europe, especially Vienna. Members of the staff of the Zentralanstalt had not only made temperature surveys and profiles through day and night, but also while traveling by auto investigated instrumentally the influence of the city on solar radiation. The reduction of sunlight intensity by city smoke in Vienna was shown to be very great, of the order of 50 per cent. After the symposium a room full of apparatus and maps and diagrams dealing with microclimatology was thrown open to inspection. Stationary and traveling instruments and observers have been used effectively in microclimatological investigations. The use of the automobile specially equipped with a psychrometer and other apparatus, is increasing rapidly. Knowledge of local differences in climate is valuable both economically and meteorologically. Farmers, orchardists, even city dwellers, are interested in a very practical way. The meteorologist sees in local differences convenient samples of equal differences in general climate at places separated by 500 to 1,000 miles.

The papers of the Paris Congress will soon be published in the proceedings of the Congress. The transactions of the several international commissions will be published by the secretariat of the International Meteorological Organization, and the papers presented at the Vienna meeting will be published in full or in abstract in the Meteorologische Zeitschrift.

LOCARNO MEETING OF THE METEOROLOGICAL COMMITTEE, OCTOBER, 1931

By C. F. MARVIN

During the first week of October, 1931, meetings were held at Locarno, Switzerland, of the International Meteorological Committee, under the chairmanship of Dr. Van Everdingen, including a meeting of the council and of the subcommission organization of meteorological reports over the oceans, under the chairmanship of General Delcambre. The Chief of the U. S. Weather Bureau is a member of each of these groups, and attended the meetings in person.

The matter of first importance in connection with the meeting at Locarno was the fact that the so-called executive council, consisting of representatives of five nations, one of these representatives being the president of the International Meteorological Organization, held its first meeting after it was created at the conference of directors at Copenhagen, in 1929. This was, therefore, its organization meeting. In addition to deciding upon necessary rules and regulations for accomplishing the work of the council, decisions were reached in regard to the budget and funds for the maintenance of the office of the secretariat during the forthcoming year, and the projects tentatively under way were approved. With some modifications these rules and regulations were subsequently approved by the International Meteorological Committee, and they have now become the permanent guide for this new feature of the work of the International Meteorological Organization.

The major part of the sessions of the committee was devoted to the reading of reports by the president of the Upper Air Commission, which held its meeting in Madrid recently, and the president of the Polar Year Commission, following the meeting of that and some other commissions at Innsbruck, Austria, in September. The committee devoted considerable time to discussion of the numerous resolutions that resulted from the reports mentioned, and these resolutions, with such modifications as were deemed necessary, were approved or indorsed by the International Committee.

Also meetings were held of the subcommission on organization of the meteorological work of the oceans, more particularly with reference to the ship report work from selected ships on the North Atlantic. Some of the difficulties in connection with the reception and distribution of reports were discussed, and agreements were reached with a view to realizing more uniform and better and more valuable service in the future.

Almost coincidentally with the meetings at Locarno, in connection with ship reports from the oceans, an international conference of radiomarine organizations was held in New York, at which particular consideration was given to the agreement between all radio organizations to transmit meteorological reports from ships at sea free of cost for what is called the "ship tax," in view of the important benefits that navigation, including radio interests, receive from the free dissemination by meteorological services of forecasts, warnings, and important meteorological information.

Perhaps one of the most important actions taken at the Locarno meeting was the decision that, notwithstanding the difficulty confronting the various nations at the present time, the program of intensive observational work which had been previously planned and provided for by nearly all nations for the so-called polar year, beginning with August, 1932, and extending to August, 19, 1933, should be carried through, although it was recognized that the critical situation might make it impracticable to carry out all the features of the program originally contemplated.

WHITE LIGHTNING VERSUS RED AS A FIRE HAZARD

By W. J. HUMPHREYS

Mr. Seley W. Moore, of Darby, Mont., says, in a letter dated October 14, 1931, that he spent the summers of both 1930 and 1931 on a lookout, that is, a place commanding a wide view from which watch is kept for forest fires, and that it was his observation that red lightning, though often tearing trees to pieces, seldom starts a fire. Now, it is well known that many forest fires are started by lightning, especially by that of "dry" thunderstorms—the thunderstorms whose rain, being all evaporated in mid-air, does not reach the earth. We therefore infer that if it be generally true that red lightning seldom starts a fire then the lightning of a dry thunderstorm must not be red. Indeed since in this case those portions of the electric discharges which are clearly seen occur out in the open and rainless air their light must be owing almost entirely to the two gases oxygen and nitrogen, and therefore contain too little red for that color to become conspicuous even when the lightning is a long ways off. Essentially it is white lightning or even bluish white. On the other hand, a lightning discharge through heavy rain may well dissociate some of the water, or water vapor, along its path, and thereby produce also the hydrogen spectrum, which is brilliantly red, in addition to those of the chief gases of the atmosphere, oxygen and nitrogen. In this way the lightning would, and doubtless does, become distinctly red. Apparently, then, lightning through rain is, or may be, red while that through the air where there is no rain is not red, but commonly white. Hence red lightning, being through rain, strikes only wet objects and therefore seldom starts a fire, while white lightning may, and often does, strike dry fuel which is far more easily fired than is the same sort of duff or other material when wet. In short it is not the difference between white lightning and red lightning that makes the one a greater fire hazard than the other, but the condition, wet or dry, of the combustible when struck.

SEVERAL CLOUD SPOUTS

By EDWARD M. BROOKS (Worcester, Mass.)

Several cloud spouts were recently observed from the open east slope of Mann Hill, Littleton, N. H. (lat. 44° 21′ N., long. 71° 44′ W., altitude 1,475 feet above sea level). These cloud spouts were interesting because they occurred at an unusual place and times of day; they were moving in uncommon directions; and, even though one looked like a tornado, it caused no apparent damage.

At 7:30 p. m. (E. S. T.) on July 9, 1931, while the air was calm and sultry, a dark cloud approached at a moderate speed from the north-northwest. A quarter of an hour later, a sudden breeze came over the hill from the northwest just after the front of the dense cloud had passed overhead. Suddenly at 7:50 p. m. a cloud like a puff of smoke rose at a rapid rate from a near-by valley in the southeast. But as this arose, more cloud formed below and so on until there was a ragged column of cloud between the ground and the base of the dark cloud above. This column soon became weaker as it moved southeastward. However, there were other patches below the general cloud base and ragged cones hanging half way down to the ground in the immediate vicinity; one of these, about 5 miles north of the main spout, developed into a rough column extending nearly to the ground. Some of these patches and cones converged with it, especially from the southwest, at the rate of about 35 miles per hour. By this time, 7:55 p. m., the mass, which was now a tornado cloud in the form of a dense funnel-shaped cone inside a rough cylinder of thinner cloud, had receded toward the southeast over the slope of a hill (elevation 1,200 feet above sea level). Since the elevation of the cloud base was about 2,000 feet above sea level as indicated by an observation made with a psychrometer immediately afterward, the tornado cloud was about 800 feet in height. By estimation, a certain portion of a cloud required 25 or 30 seconds to ascend from the ground to the cloud base. Hence the rate of ascent was about 30 ft./sec.

When it was at its best, the cloud spout had reached a point 1⅓ miles northeast of Wing Road (lat. 44° 19′ N., long. 71° 39′ W.). At 8:00 p. m. it had passed over the little hill into a swamp on its southeast side. But by this time the cone had broadened, become less dense, and merged with the huge cylinder, thus indicating a decrease in intensity of the whirl. At 8:05 p. m. the lower end of the column had risen from the ground and was half way to the cloud base. As the cloud spout approached Beech Hill a few minutes later, it disappeared. Except for a few scattered trees probably blown over by it, no damage was visible from the highway running northeastward from Wing Road.

During the night the northerly wind continued, but with much reduced velocity, and heavy rain fell, ceasing on the morning of July 10. At 7:45 a. m. the sky was mostly covered with dense strato-cumulus clouds moving generally from the southwest. Also there was some fog in a few valleys, especially to the southeast, but it was moving slowly from the north or northeast. At 7:55 a. m. there were a few low clouds about 8 miles to the south-southeast of us in front of Mount Garfield. At 8:00 a. m. these clouds were rising into the cloud base and soon a cloud spout had formed. The rate of ascent of cloud projections from the side of the spout was about 25 ft./sec., according to a rough angular measurement by C. F. Brooks. The spout at its best probably extended to the ground, but this is not certain since Mount Agassiz and Cleveland in Bethlehem cut out half the view. It did not last long because its top was moving in the opposite direction from its base, thus causing it to lean at the top toward the northeast and finally to separate. Other cloud spouts kept forming between 8:00 and 8:30 a. m. in various places toward the southeast, but they were weaker than those that preceded.

A TORNADO CLOUD IN THE FREE AIR

By ALFRED C. HAWKINS

A very unusual tornado cloud was observed by many people at Wilmington, Del., September 4, 1931. It was a fine summer day, with blue sky, and about 0.2 cirrus and 0.4 cumulus, the latter in small detached showers, high but only a few miles broad. Surface wind from the west, about 5 miles per hour, and cumulus in upper part moving very slowly from the west; lower dark, ragged nimbus from the west-southwest.

The largest shower was due east of Wilmington, I should judge 15 or 20 miles east of the Delaware River, over New Jersey. It was building up and backward and did not appear to move. At 5:45 p. m. a narrow white ribbon appeared in the sunlight, joining the upper part of the cumulus with a nimbus layer at the bottom. It looked like the white ribbon of smoke which an airplane laying a smoke screen might make on a long vertical dive. From 5:45 until 6:00 p. m. this tornado spout was visible, retaining the same position, but developing a bend about two-thirds of the way down, and finally fading out at the bottom, developing a thin point which ascended and descended at intervals. A bulge formed in the spout at times and traveled downward toward the bottom. We could see the spout revolving, but it was never wide at the top. At times the bottom of it glowed a beautiful rose color in the sunlight. It never reached anywhere near the ground, but simply joined the two layers of cloud. If the bottom of the cloud at the dew point were about a mile above the earth, then the spout must have been approximately half a mile high. At 6:00 p. m. some dark nimbus clouds came along and obscured the spout, although it could be seen for some time through holes in the nearer clouds.

PRELIMINARY STATEMENT OF TORNADOES IN THE UNITED STATES DURING 1931

By HERBERT C. HUNTER

(Weather Bureau, Washington, February 2, 1932)

In advance of the final study of windstorms of 1931, which probably will be finished during next summer, and in accordance with the practice of recent years, a preliminary statement is made in the December issue of the REVIEW of the results derived from information secured through the assistance of many observers, especially the several sections directors. Practically all this material has been employed in compiling the monthly tables of "Severe Local Storms."

The number of tornadoes and the damage they caused were considerably less than for any other recent year, and it is especially gratifying that the loss of life was less than half the least in any of the preceding 15 years. The greatest loss of any month was in December although this usually is the season of least tornado activity.

TORNADOES AND PROBABLE TORNADOES

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Number	3	0	5	2	12	20	11	11	12	4	4	5	89
Deaths	7	----	3	0	2	2	0	1	5	0	0	14	34
Damage [1]	48	----	115	6	272	215	39	135	828	80	16	72	1,826

TORNADIC WINDS AND POSSIBLE TORNADOES [2]

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Number	0	0	0	1	0	1	0	0	1	0	0	0	3
Deaths	----	----	----	0	----	0	----	----	0	----	----	----	0
Damage [1]	----	----	----	2	----	25	----	----	3	----	----	----	30

[1] In thousands of dollars.
[2] Some of these, in the final study, may be classed as not tornadoes.

THE WEATHER OF 1931 IN THE UNITED STATES

By HERBERT C. HUNTER

The year was marked by unusual warmth over the greater part of the country, and was somewhat warmer than normal in all but a very few small areas. Temperatures were particularly above normal in the months usually styled the winter months—December, January, and February—also considerably in the autumn months and July.

Of the 12 months only March averaged cooler than normal, on the basis of the district departures shown in Table 1, although May was practically normal in the country as a whole.

The accompanying temperature-departure chart, like the right-hand column of Table 1, indicates that the north-central portion of the country had the greatest positive departure for the year as a whole, as it also had in 1930, 1928, and 1921. In general, 1931 and 1921 were the warmest years experienced in the United States during a considerable period.

The smallest departures were found in the Florida Peninsula and the Southern Slope. Indeed, the former averaged more than half a degree below normal temperature during the 11-month period, January to November, but the warmest December of record succeeded, making the district temperature average for the entire year slightly above normal.

The precipitation was deficient in the country as a whole, but to a considerably less extent than in 1930. Once more the Florida Peninsula shows the largest excess for the year, but a considerably smaller excess than for 1930. The Southwest recorded more precipitation than normal, particularly the South Pacific district. The Middle Atlantic, Ohio Valley, and North Pacific districts, where 1930 saw marked deficiencies, experienced deficiencies also in 1931, as a whole; but shortages were less, particularly in the Ohio Valley and the North Pacific areas; also the distribution from month to month was not so unfavorable.

The South Atlantic district had a considerable shortage, notably during the 6-month period, June to November. The Northern Slope and North Dakota had marked deficiencies of rainfall starting in April and lasting through substantially all the months of the growing season.

During every month several districts received greater precipitation than normal and several others less than normal. As Table 2 indicates, the month of June had the greatest deficiency over the country as a whole, though February and May likewise fell short to a considerable extent. December alone showed an excess more than very slight, when all the districts were averaged.

It should be remarked that the two charts and the tables are based on reports from about 200 Weather Bureau stations and that a larger number and better distribution of the reporting stations would probably give a somewhat different result, especially as to the areas of positive and negative departures.

TABLE 1.—*Monthly and annual temperature departures, 1931*

District	January	February	March	April	May	June	July	August	September	October	November	December	Average
New England	+1.1	+1.7	+3.6	+2.7	+1.6	+0.8	+2.0	+1.4	+3.4	+3.7	+6.4	+3.7	+2.7
Middle Atlantic	+2.5	+2.9	−0.7	+0.1	+0.1	+0.6	+2.9	+0.7	+5.1	+3.4	+7.7	+7.2	+2.7
South Atlantic	+0.5	+1.1	−4.1	−1.4	−1.7	+0.9	+2.7	+0.1	+4.1	+2.8	+6.5	+8.5	+1.7
Florida Peninsula	−3.1	−1.8	−5.4	−1.8	−0.1	+0.5	+1.6	+0.9	+0.4	+0.9	+1.7	+8.3	+0.2
East Gulf	−0.4	+1.1	−5.4	−1.9	−2.8	+1.7	+1.4	−1.2	+4.1	+3.5	+6.8	+8.2	+1.3
West Gulf	+2.2	+3.7	−5.5	−3.9	−3.6	+0.9	+0.6	−1.2	+4.5	+5.9	+6.5	+3.0	+1.1
Ohio Valley and Tennessee	+3.0	+4.3	−4.3	−0.1	−2.7	+2.0	+3.1	−0.4	+5.2	+3.3	+9.0	+8.4	+1.3
Lower Lakes	+2.6	+4.4	+1.2	+1.8	0.0	+0.9	+4.0	+1.7	+5.5	+4.2	+9.1	+6.7	+3.5
Upper Lakes	+6.4	+9.6	+2.2	+2.1	−0.5	+3.1	+4.2	+1.7	+6.1	+5.4	+8.7	+8.1	+4.8
North Dakota	+16.4	+20.4	+3.7	+3.8	−0.5	+5.5	+2.6	+1.5	+5.1	+4.6	+3.9	+9.1	+6.3
Upper Mississippi Valley	+9.4	+11.6	−0.3	+2.3	−3.0	+5.3	+3.8	+0.7	+6.9	+5.3	+9.2	+10.3	+5.1
Missouri Valley	+11.1	+12.8	−1.1	+1.7	−2.5	+6.7	+3.6	+0.8	+7.5	+4.6	+5.3	+7.8	+4.9
Northern Slope	+10.1	+11.0	+1.2	+1.5	+0.9	+5.5	+3.2	+2.6	+3.4	+2.8	−2.4	+1.1	+3.4
Middle Slope	+6.8	+8.2	−4.0	−1.0	−2.6	+4.9	+2.6	−0.1	+7.9	+4.7	+1.8	+5.6	+2.9
Southern Slope	+1.7	+3.8	−5.4	−4.1	−3.9	+1.6	0.0	−0.6	+6.4	+5.5	+2.7	−0.1	+0.6
Southern Plateau	+1.4	+2.4	+1.2	+3.1	+2.8	+1.4	+3.9	+0.8	+2.2	+2.9	−1.9	−2.6	+1.5
Middle Plateau	+0.2	+3.6	+0.2	+2.3	+3.3	+3.9	+6.1	+3.5	+1.0	+3.8	−4.3	−5.1	+1.5
Northern Plateau	+3.5	+2.1	+0.6	+0.6	+4.2	+2.0	+4.1	+3.2	+1.1	+1.6	−4.1	−3.3	+1.3
North Pacific	+5.4	+3.0	+2.3	+3.6	+4.0	+0.9	+2.0	+0.6	+1.0	+1.0	−2.4	−0.4	+1.8
Middle Pacific	+2.0	+3.5	+3.7	+4.1	+5.4	+1.5	+4.2	+1.3	−0.3	−0.6	−2.9	−1.8	+1.7
South Pacific	+3.9	+4.1	+5.8	+6.0	+5.7	+2.3	+6.3	+4.6	+1.3	+2.6	−2.0	−1.1	+3.3
United States	+4.1	+5.4	−0.5	+1.0	+0.2	+2.5	+3.1	+1.1	+3.9	+3.4	+3.1	+3.9	[1] +2.6

[1] Annual departure.

TABLE 2.—*Precipitation departures, monthly and annual, 1931*

District	January	February	March	April	May	June	July	August	September	October	November	December	Sum
New England	−0.4	−1.0	+0.7	−0.2	+0.8	+2.1	+0.5	+0.1	−0.4	0.0	−2.1	−0.2	−0.1
Middle Atlantic	−1.4	−1.4	+0.1	−0.3	+0.9	−0.4	+0.6	+1.0	−1.2	−1.4	−1.9	−1.1	−6.5
South Atlantic	−1.2	−1.8	−0.2	−0.4	+0.6	−2.4	−0.3	−0.4	−3.0	−2.5	−1.9	+2.3	−11.2
Florida Peninsula	+2.4	+0.7	+3.8	+3.0	−0.9	−5.0	−1.2	−0.7	+5.3	−1.1	−1.3	+0.4	+5.4
East Gulf	−1.4	−1.9	−1.2	−1.7	−0.9	−2.8	+1.4	+0.7	−2.9	−0.9	−1.6	+3.9	−9.3
West Gulf	+0.6	+1.2	0.0	−0.7	−2.2	−1.2	+0.2	−0.3	−2.5	−0.6	+0.1	+2.2	−3.2
Ohio Valley and Tennessee	−2.6	−0.6	−1.4	−0.2	−0.5	−0.8	+0.5	+0.4	+0.4	−0.1	+0.1	+1.7	−3.1
Lower Lakes	−0.5	−1.0	−0.5	+0.3	+0.2	−0.7	−0.4	−0.6	+0.3	−0.7	−0.4	0.0	−4.0
Upper Lakes	−0.7	−0.8	+0.2	−1.1	−0.3	0.0	−0.6	−0.8	+1.4	+0.2	+1.1	−0.3	−1.7
North Dakota	−0.4	−0.1	+0.3	−1.2	−1.0	−1.4	+0.4	−0.2	+0.2	+0.3	−0.1	−0.1	−3.3
Upper Mississippi Valley	−1.0	−0.6	−0.1	−0.8	−1.1	−0.1	−1.1	+0.1	+0.9	+0.5	+3.0	+0.6	+0.3
Missouri Valley	−0.6	−0.2	0.0	−0.9	−0.5	−2.0	−1.2	+1.0	+0.2	−0.2	+3.2	+0.9	−0.3
Northern Slope	−0.6	−0.3	0.0	−0.6	−1.2	−0.9	−0.3	−0.6	0.0	−0.3	+0.2	−0.3	−4.9
Middle Slope	−0.4	+0.2	+0.6	+0.3	−0.8	−1.6	−1.4	−0.2	−0.6	−0.6	+2.5	−0.3	−2.3
Southern Slope	+1.0	+0.9	+0.1	+0.9	+0.1	−0.8	−0.8	−0.4	−2.4	+1.1	+0.8	+0.7	+1.2
Southern Plateau	−0.3	+0.7	−0.2	+0.8	−0.3	+0.2	−0.8	+0.8	+0.6	−0.2	+0.6	+0.1	+2.0
Middle Plateau	−0.6	−0.4	−0.5	+0.1	−0.5	−0.1	−0.1	−0.1	+0.1	−0.2	+0.6	+0.2	−1.5
Northern Plateau	−0.5	−0.7	+1.1	−0.6	−1.2	−0.2	−0.4	−0.4	0.0	−0.2	+0.1	+0.8	−2.2
North Pacific	0.0	−1.7	+1.5	−0.3	−1.3	+0.3	−0.6	−0.6	+0.9	0.0	−0.9	+0.8	−1.9
Middle Pacific	−0.2	−2.4	−2.0	−1.3	−0.1	+0.3	0.0	0.0	−0.5	−0.5	0.0	+3.7	−3.0
South Pacific	+1.1	+0.5	−1.9	+0.8	+0.3	+0.3	0.0	0.0	−0.1	−0.6	+0.9	+2.3	+3.6
United States	−0.4	−0.5	0.0	−0.2	−0.5	−0.8	−0.3	−0.1	−0.2	−0.4	+0.1	+0.9	−2.4

BIBLIOGRAPHY

C. FITZHUGH TALMAN, in charge of Library

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

American national red cross.
Texas tornadoes and storms of May, 1930. 6 p. m. 28 cm. [Manifolded.]

Bentley, W. A., & Humphreys, W. J.
Snow crystals. 1st ed. New York. 1931. ix, 227 p. incl. front., illus. plates. 31½cm.

Bongards, H.
Lambrechts graphische Psychrometertafel für starkbewegte Luft. Luftgeschwindigkeit ≧2 m. p. s. n. p. n. d. chart (folded.) 22½ x 26½ cm.

Hannay, A. M., *comp.*
Influence of weather on crops: 1900–1930. A selected and annotated bibliography. [Washington. 1931.] 246 p. 23½ cm. (U. S. Agric. dept. Misc. pub. no. 118.)

Lindskog, Erik.
On the geographical distribution of fog in Sweden. n. p. n. d. 94 p. figs. 25 cm. (Georg. annaler. H. 1, 1931.)

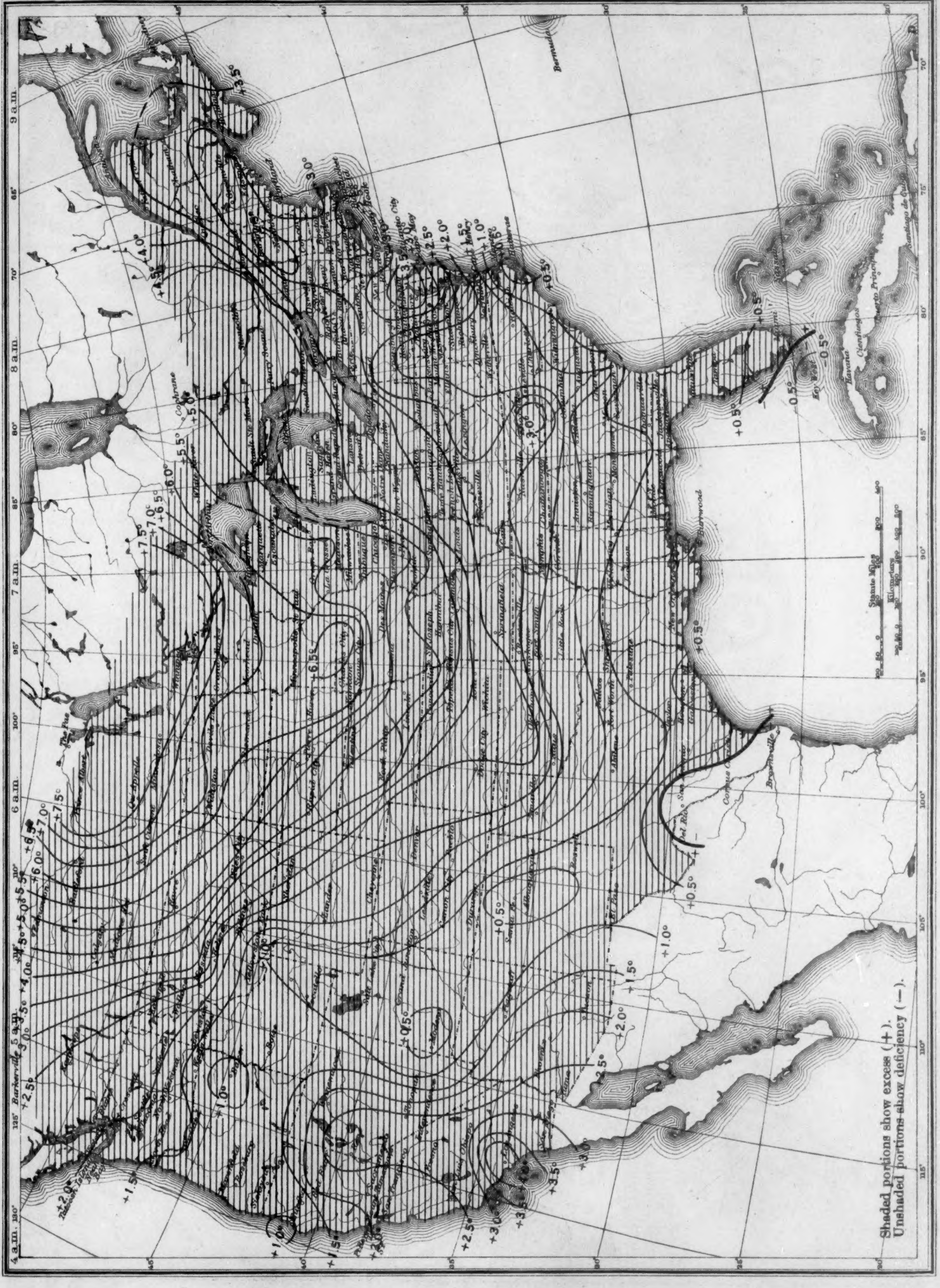
Mellor, H. B., *& others.*
Studies of ultra-violet in daylight. 17 p. illus. 23 cm. (Paper presented before the silver anniv. conven. of the Illum. engin. soc., Pittsburgh, Pa., Oct. 13–16, 1931.)

Nichols, L. H.
Fourth report to the Quebec forest industries association, limited. The burning of settler's slash and meteorological conditions in the province of Quebec during 1931. Quebec. 1931. 22 p. plates. charts. 28 cm.

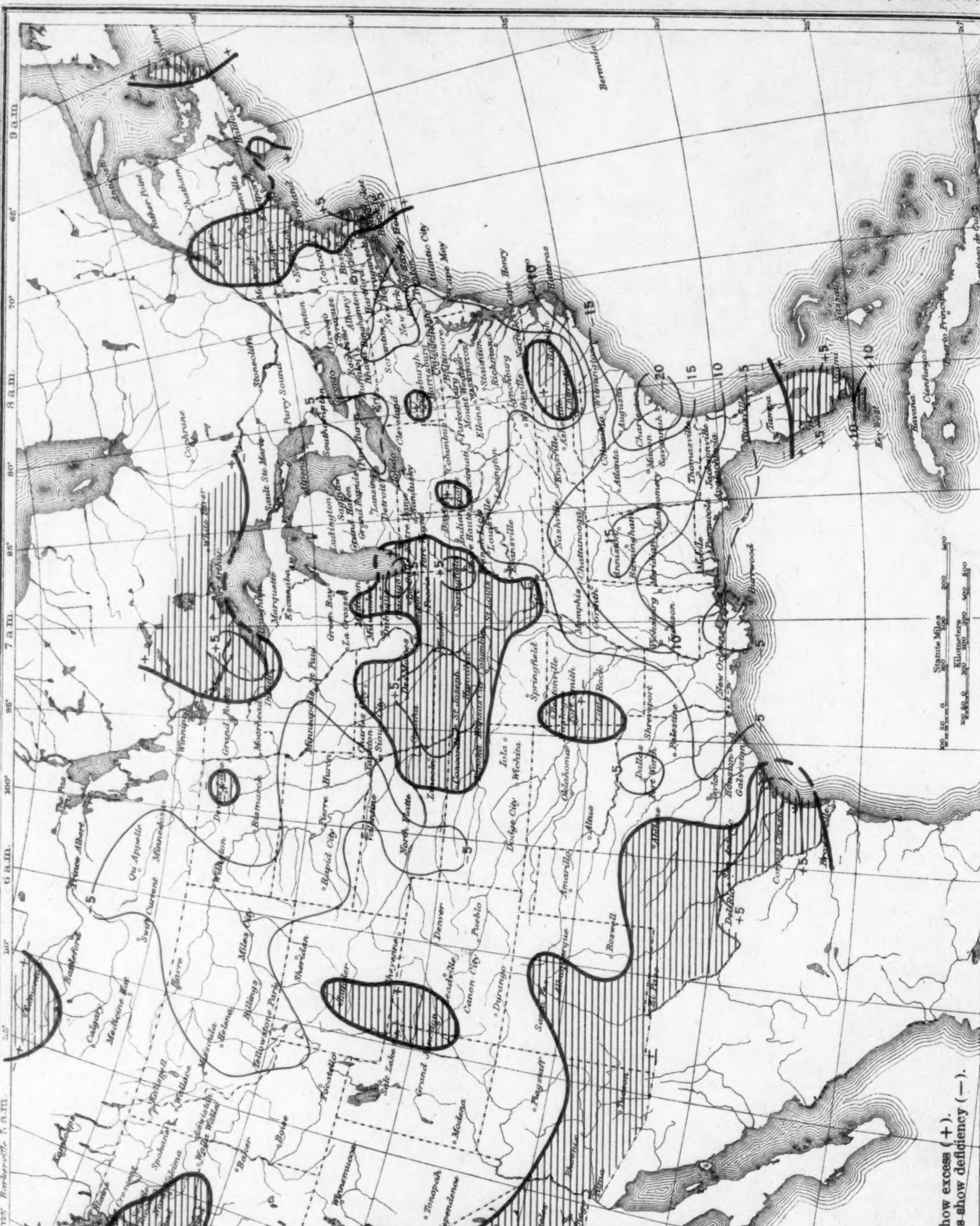
Peppler, W.
Ergebnisse der mehrjährigen Messungen der Ortshelligkeit am Bodensee. p. 157–189. figs. 23 cm. (Sonderab.: 57. Hefte der Schrift. des Ver. für Gesch. des Bodensees und seiner Umgebung.) (Arbeiten der Drachenstation am Bodensee.)

Prochnow, Oskar.
Wolken. Berlin. [c. 1931.] 32 p. illus. 21 cm. (Die Brehm-Bücher Bd. 9.)

I. Annual Temperature Departures (°F.) in the United States, 1931



II. Annual Precipitation Departures (inches) in the United States, 1931



Schaffers, V.
Le paratonnerre et ses progrès récents. Louvain. 1931. 87 p. 25 cm. (Extr.: Revue des ques. sci., t. 99 et 100. mai et juil. 1931.)

Sherlock, R. H., & Stout, M. B.
Annemometer for a study of wind gusts. [Menasha.] 1931. 38 p. illus. plate (fold.) 23 cm. (Engin. research bull., no. 20, May, 1931. Univ. Mich.)

Wagner, A.
Zur Aerologie des indischen Monsuns. Leipzig. 1931. p. 196–238. figs. 22 cm. (Sonderdr.: Gerlands Beitr. zur Geophys., Bd. 30 (1931).)

Wulf, Oliver R.
Determination of ozone by spectrobolometric measurements. Washington. 1931. 12 p. figs. plates. 24½ cm. (Smith. misc. coll., v. 85, no. 9.)

SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING DECEMBER, 1931

By HERBERT H. KIMBAL, in charge, solar radiation investigations

For a description of instruments and their exposures, the reader is referred to the January, 1931, REVIEW, page 41.

Table 1 shows that solar radiation intensities averaged above the normal values for December at Washington and Madison and close to normal at Lincoln.

Table 2 shows an excess in the total solar radiation received on a horizontal surface at Chicago, New York, and Miami as compared with the December normals for the respective stations; close to normal at Pittsburgh, and a deficit at Washington, Madison, Lincoln, Twin Falls, Fresno, Gainesville, and La Jolla. The last line in the table gives annual departures in percentages of annual totals.

Skylight polarization measurements made on 4 days at Washington give 61 for the mean percentage of polarization, with a maximum of 65 per cent on the 2d and 6th. At Madison, polarization measurements made on three days early in the month give a mean of 72 per cent with a maximum of 77 per cent on the 1st. These are above the corresponding averages for each station in December.

TABLE 1.—*Solar radiation intensities during December, 1931*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Dec. 2	2.49	0.79	0.93	1.09	1.31			1.12	0.95	0.85	2.74
Dec. 7	3.15		1.00	1.18	1.36			1.12	0.86	0.75	2.26
Dec. 15	3.30	0.90	1.06	1.11	1.33			1.06	0.83	0.58	2.87
Dec. 16	3.81		0.97	1.13	1.38						2.74
Dec. 23	8.18	0.93									6.02
Means		0.87	0.99	1.13	1.34			1.10	0.88	0.73	
Departures		+0.08	+0.09	+0.08	+0.11			+0.06	−0.03	−0.06	

Madison, Wis.

Date	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Dec. 1	2.49				1.42						1.98
Dec. 2	2.87			1.23							3.00
Dec. 3	3.30	0.95	1.04	1.18							3.15
Dec. 7	1.37			1.34				1.26			1.24
Dec. 14	2.36	1.10	1.15	1.10							2.26
Means		(1.02)	(1.10)	1.21	(1.42)			(1.26)			
Departures		+0.06	±0.00	±0.00	+0.07			+0.02			

Lincoln, Nebr.

Date	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Dec. 1	2.36	1.05	1.13	1.29				1.23	1.09	0.88	3.30
Dec. 2	3.00			1.20				1.23	1.12	1.02	4.17
Dec. 11	6.50		0.99	1.19				1.25	1.11	1.00	3.81
Dec. 14	2.26	0.90	1.09	1.26				1.23	1.11		3.00
Dec. 15	2.62	0.79	1.04	1.10				1.21	1.07	1.05	3.30
Dec. 16	3.15	0.84	0.99	1.15				1.15	1.04		3.63
Means		0.90	1.05	1.20				1.22	1.09	0.99	
Departures		−0.04	−0.01	−0.02				+0.02	+0.02	+0.03	

[1] Extrapolated.

TABLE 2.—*Total solar radiation (direct + diffuse) received on a horizontal surface*

[Gram-calories per square centimeter]

Week, beginning	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Pittsburgh	Gainesville	Fresno	La Jolla	Miami	Fairbanks
	Average daily totals											
1931	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Dec. 3	156	115	110	90	112	103	85	142	163	220	376	2.0
Dec. 10	133	113	156	112	85	163	78	187	170	250	367	1.5
Dec. 17	118	74	137	90	83	118	82	189	169	188	364	1.2
Dec. 24	137	66	87	64	160	101	65	204	122	202	274	1.7
	Departures from weekly normals											
Dec. 3	+8	−6	−55	+18	+22	−37	+5	−76	−14	−42	+73	----
Dec. 10	−5	+1	−1	+40	−5	+37	+10	−22	+2	−10	+69	----
Dec. 17	−22	−47	−33	+13	−12	−10	+15	−14	+8	−69	+86	----
Dec. 24	−5	−58	−88	−16	+58	−51	−19	−36	−25	−36	−4	----
	Departures from annual normals											
Gr. cal./cm.²	−1,750	+1,965	−445	+2,938	+2,893	−5,846	−1,420	----	+1,718	----	----	----
Percentage	−1.4	+1.2	−0.3	+3.2	+3.1	−3.9	----	----	+1.1	----	----	----

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, Perkins, and Mount Wilson observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic Diff. long.	Heliographic Longitude	Heliographic Latitude	Area Spot	Area Group	Total area for each day
1931	*h m*	°	°	°			
Dec. 1 (Mount Wilson)	13 50	+47.0	311.5	+13.0		9	
		+67.0	331.5	+10.0		137	146
Dec. 2 (Naval Observatory)	10 30		No spots				
Dec. 3 (Naval Observatory)	10 33		No spots				
Dec. 4 (Mount Wilson)	12 0	−63.0	162.9	+12.0		67	67
Dec. 5 (Naval Observatory)	10 35		No spots				
Dec. 6 (Naval Observatory)	10 23	−76.0	124.4	+12.0	31		31
Dec. 7 (Naval Observatory)	10 36	−54.0	133.1	+11.5		170	170
Dec. 8 (Naval Observatory)	12 47	−40.0	132.8	+11.5		278	278
Dec. 9 (Yerkes Observatory)	15 9	−28.5	129.9	+10.4	5		
		−27.7	130.7	+11.7		138	
		−27.7	130.7	+10.6	17		
		−27.6	130.8	+10.0	17		
		−26.1	132.3	+10.0	3		
		−25.2	133.2	+13.8	5		
		−25.1	133.3	+13.0	3		
		−25.1	133.3	+12.2		14	
		−22.8	135.6	+12.5	107		
		−21.6	136.8	+11.9	210		519
Dec. 10 (Naval Observatory)	10 17	−38.0	109.8	+4.0		62	
		−14.0	133.8	+11.0		340	402
Dec. 11 (Naval Observatory)	11 20	−23.0	111.0	+4.0		154	
		−1.0	133.0	+11.0		401	555
Dec. 12 (Yerkes Observatory)	14 18	−10.2	109.1	+4.3	7		
		−9.7	109.6	+5.3	5		
		−9.3	110.0	+4.1	2		
		−6.3	113.0	+4.3		48	
		−5.4	113.9	+4.7	22		
		+10.5	129.8	+10.2	88		
		+11.1	130.4	+11.0	2		
		+11.9	131.2	+11.2	2		
		+13.6	132.9	+11.7		169	
		+16.6	135.9	+12.2	37		
		+17.7	137.0	+12.4	37		419
Dec. 13 (Mount Wilson)	11 30	+4.0	111.6	+5.0		41	
		+26.0	133.6	+12.0		298	339

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic			Area		Total area for each day
		Diff. long.	Longitude	Latitude	Spot	Group	
1931	h m	°	°	°			
Dec. 14 (Naval Observatory)	12 43	+21.0	114.7	+4.0	15	------	------
		+39.0	132.7	+12.0	------	278	293
Dec. 15 (Naval Observatory)	11 20	+33.0	114.3	+4.0	25	------	------
		+50.0	131.3	+11.0	------	123	148
Dec. 16 (Naval Observatory)	10 30	+47.0	115.6	+4.0	15	------	------
		+63.0	131.6	+11.0	------	93	108
Dec. 17 (Naval Observatory)	10 39	+78.0	133.4	+11.0	------	93	93
Dec. 18 (Naval Observatory)	11 36	−69.0	332.7	+11.0	93	------	93
Dec. 19 (Naval Observatory)	10 37	−56.0	333.0	+11.5	93	------	93
Dec. 20 (Naval Observatory)	10 48	−41.5	334.3	+11.0	------	46	46
Dec. 22 (Yerkes Observatory)	14 23	−12.6	334.9	+12.1	15	------	15
Dec. 23 (Naval Observatory)	10 37	−4.0	332.3	+11.0	------	31	------
		+46.0	22.3	+14.0	31	------	62
Dec. 24 (Mount Wilson)	11 0	−80.0	242.9	−2.0	------	47	------
		−80.0	242.9	−12.0	84	------	------
		+5.0	327.9	+9.5	------	28	------
		+59.5	22.4	+11.0	------	27	186
Dec. 25 (Yerkes Observatory)	13 26	−64.9	243.6	−13.4	284	------	------
		−59.0	249.5	−2.5	19	------	303
Dec. 26 (Naval Observatory)	11 24	−54.0	242.4	−12.0	108	------	------
		−47.0	249.4	−1.5	15	------	123
Dec. 27 (Naval Observatory)	14 10	−40.0	241.7	−14.0	139	------	139
Dec. 29 (Naval Observatory)	15 2	−13.0	241.9	−13.0	------	139	139
Dec. 30 (Naval Observatory)	12 49	−1.0	241.9	−13.0	------	139	139
Mean daily area for December	------	------	------	------	------	------	175

PROVISIONAL SUN-SPOT RELATIVE NUMBERS, FOR DECEMBER, 1931

(Data dependent alone on observations at Zurich and its station at Arosa)

[Data furnished through the coutresy of Prof. W. Brunner, University of Zurich, Switzerland]

December, 1931	Relative numbers	December, 1931	Relative numbers	December, 1931	Relative numbers
1	20	11	a 35	21	8
2	16	12	37	22	16
3	7?	13	a 38	23	17
4		14	37	24	d 23
5	0	15	26	25	31
6	Ec 7	16		26	31
7	12	17	15	27	31
8	13	18	8	28	15
9	24	19	8	29	9
10	Ec —	20	8	30	a 11
				31	9

Mean: 28 days=18.3.

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[The Aerological Division, W. R. GREGG, in charge]

By L. T. SAMUELS

Free-air temperatures were decidedly above normal and relative humidities were close to normal at all stations for December.

At the 1,000-meter level the resultant wind directions were close to normal at the northern stations but contained a considerably greater south component than normal at most of the southern stations. Resultant velocities were somewhat above normal at most stations.

At 3,000 meters the resultant directions were close to normal except at the extreme southern stations. At Key West a pronounced easterly component persisted to 4,000 meters as compared to the normal westerly direction at that level. Resultant velocities at 3,000 meters exceeded the normal appreciably in New England and at some southern stations.

TABLE 1.—*Mean free-air temperatures and humidities obtained by airplanes (or kites) during December, 1931*

TEMPERATURE (°C)

Altitude (meters) m. s. l.	Chicago, Ill.[1] (190 meters)	Cleveland, Ohio[1] (245 meters)	Dallas, Tex.[1] (149 meters)	Due West, S. C.[2] (217 meters)	Ellendale, N. Dak.[2] (444 meters)	Hampton Roads, Va.[3] (3 meters)	Omaha, Nebr.[1] (299 meters)	Pensacola, Fla.[3] (2 meters)	San Diego, Calif.[3] (9 meters)	Washington, D. C.[3] (2 meters)
Surface	1.7	2.3	7.2	9.1	−6.0	8.1	0.1	16.3	12.4	3.2
500	1.7	2.3	8.7	9.8	−5.4	7.2	0.7	15.8	10.8	4.6
1,000	1.3	1.5	8.6	9.9	−1.0	6.1	2.4	15.7	8.7	4.2
1,500	0.9	0.3	8.0	9.5	−0.1	------	3.0	------	------	------
2,000	0.0	−0.8	6.7	7.9	−1.9	4.1	1.7	12.1	4.9	1.8
2,500	−1.7	−2.5	4.8	6.0	−4.3	------	−0.6	------	------	------
3,000	−4.0	−4.8	2.6	3.4	−6.8	0.6	−3.1	7.0	0.9	−0.4
4,000	−9.4	−9.3	−3.9	------	−13.7	------	−9.5	------	−5.7	------
5,000	−16.5	−14.6	−11.0	------	−19.7	------	−16.7	------	−13.6	------
6,000	------	------	−16.2	------	------	------	−23.9	------	------	------

RELATIVE HUMIDITY (PER CENT)

Altitude (meters) m. s. l.	Chicago	Cleveland	Dallas	Due West	Ellendale	Hampton Roads	Omaha	Pensacola	San Diego	Washington
Surface	85	82	86	87	88	76	86	90	59	77
500	79	78	72	76	85	66	79	82	58	67
1,000	67	72	58	66	60	64	60	73	54	60
1,500	57	63	51	54	52	------	43	------	------	------
2,000	49	56	45	53	56	41	37	63	40	46
2,500	45	50	42	42	56	------	36	------	------	------
3,000	44	49	37	34	56	32	36	65	34	32
4,000	40	44	35	------	83	------	35	------	36	------
5,000	30	39	36	------	65	------	32	------	60	------
3,000	------	------	10	------	------	------	24	------	------	------

[1] Airplanes (Weather Bureau). [2] Kites. [3] Airplanes (Navy).

TABLE 2.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a. m. (E. S. T.) during December, 1931*

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,528 meters)		Brownsville, Tex. (12 meters)		Burlington, Vt. (132 meters)		Cheyenne, Wyo. (1,873 meters)		Chicago, Ill. (198 meters)		Cleveland, Ohio (245 meters)		Dallas, Tex. (154 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Havre, Mont. (762 meters)		Jacksonville, Fla. (14 meters)		Key West Fla. (11 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	N 29 E	1.1	N 78 W	1.6	S 27 W	1.3	N 74 W	4.2	S 76 W	0.9	S 69 W	1.9	S 87 W	0.5	N 48 E	1.2	N 60 W	1.0	S 66 W	2.2	N 48 E	0.7	S 78 E	3.4
500			N 9 W	1.7	S 64 W	4.5			S 86 W	4.2	S 77 W	5.7	S 54 W	3.2	N 65 W	1.4	N 65 W	1.4			S 12 E	3.8	S 69 E	8.9
1,000			S 22 W	3.0	N 83 W	7.4			S 84 W	6.7	N 84 W	7.9	S 70 W	4.2	S 83 W	2.9	N 51 W	3.6	S 62 W	6.9	S 5 W	3.8	S 59 E	8.0
1,500			S 19 W	4.4	N 62 W	10.6			N 83 W	12.8	N 87 W	10.7	S 49 W	5.5	S 84 W	5.8	N 60 W	5.0	S 79 W	9.5	S 41 W	4.4	S 57 E	6.0
2,000	N 23 W	1.8	S 72 W	5.2	N 62 W	14.1	N 82 W	7.4	N 87 W	10.3	N 85 W	11.3	S 60 W	6.9	W	8.8	N 64 W	8.3	N 89 W	9.3	S 57 W	5.2	S 54 E	5.1
2,500	N 71 W	3.9	S 44 W	7.0	N 61 W	16.3	N 86 W	9.3			N 87 W	12.9	S 64 W	8.9	N 83 W	8.1	N 70 W	8.5	N 87 W	9.4	S 44 W	5.5	S 52 E	3.9
3,000	N 71 W	5.8	S 51 W	9.2	N 55 W	21.3	N 82 W	7.1					S 67 W	10.5	S 89 W	8.9	N 76 W	9.9	N 87 W	10.7			S 57 E	4.3
4,000	N 79 W	8.7					S 89 W	9.0					S 80 W	10.2			N 70 W	14.5					S 40 E	3.4
5,000	S 77 W	7.2					S 88 W	6.8																
6,000							N 72 W	2.4																

Altitude (meters) m. s. l.	Los Angeles, Calif. (217 meters)		Medford, Oreg. (410 meters)		Memphis, Tenn. (89 meters)		New Orleans, La. (25 meters)		Oakland, Calif. (8 meters)		Oklahoma City, Okla. (392 meters)		Omaha, Nebr. (299 meters)		Phoenix, Ariz. (356 meters)		Salt Lake City, Utah (1,294 meters)		Sault Ste. Marie, Mich. (198 meters)		Seattle, Wash. (14 meters)		Washington, D. C. (10 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	N 42 W	0.3	S 58 E	0.7	S 2 E	0.7	N 62 E	1.2	S 68 E	1.6	S 64 W	0.8	S 30 E	0.9	S 61 E	1.5	S 26 E	3.2	S 75 E	0.2	S 49 E	2.1	N 51 W	1.4
500	N 73 E	0.4	S 56 E	1.5	S 16 W	0.8	S 32 E	2.9	S 26 E	2.3	S 34 W	2.1	S 58 W	2.9	S 77 E	2.3			N 55 W	0.1	S 3 E	6.6	N 70 W	7.3
1,000	N 30 E	0.3	S 17 E	5.6	S 65 W	2.6	S 29 W	4.8	S 47 W	1.8	S 66 W	3.7	S 60 W	8.3	S 78 E	1.9			N 65 W	2.7	S 16 W	9.8	N 73 W	9.6
1,500	N 60 W	1.9	S 26 W	6.4	S 52 W	4.2	S 38 W	2.5	S 55 W	4.0	S 57 W	5.1	S 67 W	8.6	S 37 E	1.5	S 11 E	4.3	N 46 W	4.5	S 23 W	11.7	N 68 W	13.6
2,000	N 68 W	3.7	S 35 W	9.9	S 89 W	5.1	S 54 W	7.4	S 62 W	4.5	S 72 W	6.0	N 86 W	8.5	S 22 W	0.3	S 6 W	5.9	N 44 W	6.3	S 19 W	11.3	N 70 W	15.0
2,500	N 62 W	3.4	S 41 W	10.9	S 85 W	7.5	S 57 W	8.0	S 58 W	5.1	S 79 W	6.9	S 84 W	9.6	N 89 W	2.6	S 20 W	5.5	N 53 W	8.6				
3,000	N 47 W	3.8	S 44 W	12.3	N 78 W	10.8	S 52 W	5.8	S 72 W	3.4	S 78 W	8.9	N 89 W	9.4	N 73 W	4.4	S 48 W	3.9	N 34 W	7.1				
4,000			S 44 W	9.6					S 67 W	2.5	S 85 W	5.8	N 80 W	10.5	N 83 W	7.5	N 57 W	5.2						
5,000																								

TABLE 3.—*Observations by means of airplanes, kites, captive and limited-height sounding balloons during December, 1931*

	Dallas, Tex.[1]	Due West, S. C.[2]	Ellendale, N. Dak.[2]	Chicago, Ill.[1]	Cleveland, Ohio[1]	Omaha, Nebr.[1]
Mean altitudes, meters, m. s. l., reached during month	5,285	2,091	3,192	4,678	4,914	5,838
Maximum altitudes, meters, m. s. l., reached	5,982	3,570	5,161	5,273	5,671	6,547
Number of flights made	32	29	28	30	30	26
Number of days on which flights were made	31	29	28	30	30	25

[1] Airplanes. [2] Kite.

AEROLOGICAL OBSERVATIONS FOR THE YEAR 1931

[The Aerological Division, W. R. Gregg, in charge]

By L. T. SAMUELS

Table 1 shows the mean free-air temperatures and relative humidities for the year at Due West, Ellendale, and Washington, D. C., and for the parts of the year indicated at the other stations. Kite observations were discontinued during the year at Broken Arrow, Groesbeck, and Royal Center and regular daily airplane observations started at Chicago, Cleveland, Dallas, and Omaha.

An inspection of the departures from the normal free-air temperatures (not shown in table) for the corresponding periods at the various stations shows small negative values at all levels at Due West and moderately large positive departures at Ellendale and Washington, where full year records were obtained. Approximate normals for Dallas were obtained by interpolating latitudinally between Groesbeck and Broken Arrow. From these it is found that the free-air temperatures at Dallas and Omaha (the latter based on normals of the Drexel, Nebr., kite station) for the latter half of the year were above normal at all levels. The largest departures occurred at Omaha where they were nearly 4° C. at the 2,500 meter level. Positive departures of equal magnitude are found when the mean temperatures for Chicago are compared with the normals for Royal Center, situated 100 miles to the southeast.

TABLE 1.—*Mean free-air temperatures and humidities obtained by airplanes (or kites) during year 1931*

TEMPERATURE (°C)

Altitude (meters) m. s. l.	Broken Arrow, Okla.[1] (233 meters)	Chicago, Ill.[2] (190 meters)	Cleveland, Ohio[2] (245 meters)	Dallas, Tex.[2] (149 meters)	Due West, S. C. (217 meters)	Ellendale, N. Dak. (444 meters)	Groesbeck, Tex.[3] (141 meters)	Omaha, Nebr.[4] (299 meters)	Royal Center, Ind.[5] (225 meters)	Washington, D. C. (Naval Air Sta.) (3 meters)
Surface	9.3	12.6	12.4	18.2	15.3	7.3	10.4	10.4	8.3	11.8
500	8.6	13.4	13.3	19.3	14.5	7.3	9.8	11.1	6.7	11.7
1,000	7.0	12.8	12.8	18.6	12.6	7.5	7.9	12.3	4.7	10.2
1,500	4.9	10.6	10.4	16.6	10.0	6.1	6.5	11.3	2.7	
2,000	2.8	8.0	8.1	14.1	7.5	3.9	4.5	9.3	0.7	5.8
2,500	0.2	5.5	5.8	11.5	4.9	1.2	2.1	6.8	−1.3	
3,000	−2.4	2.8	3.4	8.8	2.2	−1.6	−0.4	3.9	−3.5	1.4
4,000	−8.6	−2.9	−1.5	2.5	−3.8	−7.5	−6.5	−2.6	−8.8	−3.8
5,000	−13.5	−8.9	−6.7	−2.0	−9.8	−13.9		−9.4	−14.7	−10.0
6,000			−12.3	−8.0		−19.6		−16.6	−21.6	

RELATIVE HUMIDITY PER CENT

Altitude (meters) m. s. l.	Broken Arrow	Chicago	Cleveland	Dallas	Due West	Ellendale	Groesbeck	Omaha	Royal Center	Washington
Surface	72	84	83	79	74	72	77	82	74	74
500	67	73	75	71	69	71	67	75	73	63
1,000	62	65	67	63	64	60	61	60	69	58
1,500	59	61	65	60	62	56	53	53	63	
2,000	54	57	61	58	59	54	50	48	50	54
2,500	52	52	55	55	55	54	48	45	56	
3,000	51	50	51	51	51	54	42	45	55	47
4,000	47	45	43	47	48	55	46	42	54	42
5,000	39	37	40	41	56	57		40	54	28
6,000			47	51		55		37	54	

[1] January to May, inclusive, only.
[2] July to December, inclusive, only.
[3] January to April, inclusive, only.
[4] August to December, inclusive, only.
[5] January to June, inclusive, only.

The mean free-air temperatures for Royal Center for the first half of the year were slightly above the normals for the same period; those for Broken Arrow and Groesbeck for the first five and four months, respectively, were moderately below normal.

In Table 2 it will be noted that the highest average maximum altitude reached by airplane was 6,242 meters above sea level at Omaha and the highest single flight to 7,242 meters was also made at this station. An airplane flight was made on every day during the latter half of the year at Dallas; only one day was missed at Cleveland and this was due to mechanical trouble with the airplane; two days were missed at Chicago, and nine days at Omaha on account of unfavorable flying weather.

There were 14 new pilot balloon stations established and 2 closed during 1931, making a total of 69 such stations in operation at the end of the year. Of these, 3 are located in Alaska and 1 in Porto Rico.

TABLE 2.—*Observations by means of airplanes, kites, captive and limited-height sounding balloons during the year 1931*

	Broken Arrow, Okla.[1]	Chicago, Ill.[2]	Cleveland, Ohio[2]	Dallas, Tex.[2]	Due West, S. C.[1]	Ellendale, N. Dak.[1]	Groesbeck, Tex.[1]	Omaha, Nebr.[2]	Royal Center, Ind.[1]
Mean altitudes (meters), m. s. l., reached during month	2,861	4,861	5,586	5,526	2,679	3,254	2,334	6,242	3,219
Maximum altitude, (meters), m. s. l., reached	[3] 5,906	5,692	6,355	6,304	[3] 5,477	[3] 6,324	4,702	7,242	[3] 9,445
Number of flights made	165	182	183	184	362	355	99	139	182
Number of days on which flights were made	[4] 151	[5] 182	[4] 183	[5] 184	346	338	[6] 99	[7] 137	[8] 173

[1] Kites, captive or limited-height sounding balloons.
[2] Airplanes.
[3] Limited-height sounding balloon.
[4] January 1 to June 7, inclusive.
[5] July 1 to December 31, inclusive.
[6] January 1 to May 16, inclusive.
[7] August 8 to December 31, inclusive.
[8] January 1 to June 30, inclusive.

WEATHER IN THE UNITED STATES

[Climatological Division, OLIVER L. FASSIG, in charge]

THE WEATHER ELEMENTS

By M. C. BENNETT

GENERAL SUMMARY

The continuation of abnormally warm weather during December in practically all sections east of the Rocky Mountains, and generous widespread precipitation in the interior and Southern States, were the outstanding features. The temperature for the month ranged generally from 4° to 12° above normal east of the Great Plains, except that in the extreme Northeast it was not so warm. The greatest plus departures for the month extended from Kentucky, Missouri, and eastern Kansas northward. West of the Rocky Mountains, temperatures were unusually low in many places, while in the Pacific coast sections they were only slightly below the normal. The precipitation was above the average in most areas, though along much of the Atlantic coast, in the Rocky Mountain region, and eastward therefrom along the Canadian border to the Great Lakes it was generally below the normal. Between the Appalachian and Rocky Mountains, except in eastern Oklahoma and portions of the adjacent States, the amounts were unusually generous, with many sections having from one and one-half to four times the normal. It was heavy in California also, where some stations reported nearly two and one-half times the average. In the western mountains snowfall was unusually heavy, while in the East but little snow fell.

TEMPERATURE

The first half of December continued the temperature features of the latter part of November, the eastern half of the country having mild weather, as a rule, and the western half severe cold. The temperature at this time was particularly low, compared with normal, in the Plateau and Rocky Mountain regions, and the first week saw comparatively cold weather in Texas and Louisiana as well; while some portions of the Missouri Valley, the Lake region, and the extreme Northeast likewise were moderately colder than normal about the 4th to 7th.

After the middle of the month the western half of the country was usually warmer than normal, especially the Plains and Rocky Mountain regions and those far western districts which are close to the Canadian boundary. Exceptions were to be found in the middle and southern Plateau region, and in the lower half of the Rio Grande Valley where abnormal cold continued till about the 20th. This half of December was extraordinarily warm for the time of the year in the north-central portion of the country, and was far warmer than normal elsewhere east of the Plains, except in the extreme northeastern portion where it was only moderately warmer.

As a whole, December was warmer than normal in very nearly the same part of the country that November had been; that is, east of the Rocky Mountains. However, the northern portions of Washington and Idaho, almost all of Montana, and the eastern portions of Wyoming and Colorado changed from colder than normal in November to slightly warmer in December, while the middle Rio Grande Valley made the reverse change.

Parts of New York and New England averaged but slightly warmer than normal in December, but otherwise all the country from the eastern Plains region and the lower Mississippi Valley eastward was far warmer than normal. In much of Wisconsin and States adjoining, also in portions of the extreme Southeast the mean temperature was 9° to 12° above normal.

In north-central and southeastern districts the month was usually the warmest December during the last 40 years, but was not so warm as December, 1889, save in a few localities.

The highest temperatures were close to 90° in a few of the southernmost States, and not far from 60° in northern border States and in the middle Plateau region. They occurred largely about the 11th to eastward of the Mississippi River, but at various dates between the 17th and the end of the month in practically every State west of that river.

The lowest readings were much below zero in the mountainous portions of the far West, also in the Dakotas, New York, and New England. As far north as Iowa, Ohio, and the mountains of Maryland zero temperatures were not experienced, while in Florida the lowest reading was 36°. The lowest temperatures occurred usually during the first half of the month, except in some of the Atlantic States, where they occurred during the final week.

PRECIPITATION

The first fortnight brought heavy rainfall to most portions of the Gulf and South Atlantic States, and the second week saw much precipitation also in the Ohio Valley, New England, and the greater part of the far Southwest.

The third week of the month was a notable period for precipitation in the extreme Northwest, while from Alabama and northern Georgia westward to eastern Texas heavy rainfall continued. The latter part of the month saw much precipitation in the far West, especially in California; while the middle Gulf region, the Carolinas, New England, and the Missouri and lower Ohio Valleys had considerable amounts.

As a whole, December was a month of liberal precipitation, and the distribution over the country was comparatively good. In the Gulf States, the lower Mississippi Valley, and the interior of the South Atlantic States there was considerably more than normal. The immediate South Atlantic coast had usually less than normal, though sufficient, as a rule, to considerably relieve the intense dryness developed by the fall months. In Tennessee, Mississippi, Louisiana, and eastern Arkansas the heavy December rainfall was detrimental, because of large falls in the months preceding.

From North Dakota to Michigan there was scanty precipitation in the northern portions of the respective States, but about normal or somewhat more than normal in the southern portions. The middle and lower Missouri Valley generally had far more precipitation than normal. At St. Joseph, Mo., this was the wettest December of the past 20 years. The Ohio Valley and the upper Mississippi Valley from northeastern Iowa southward had usually somewhat more precipitation than normal, and the same was true of considerable portions of the lower Lake region and of northern and eastern New England. Central Kansas, western Texas, and eastern New Mexico generally received greater than average amounts. The Pacific coast region and the western half of the Plateau region had far more than normal, particularly central and southern California.

Deficiencies were noted in central and northeastern Florida, in the middle Atlantic area and southwestern New England, from central Oklahoma to southwestern Missouri, in most of Montana and of western Nebraska, and nearly everywhere near the Rocky Mountain Divide.

SNOWFALL

The features of December snowfall greatly resembled those of November. In the eastern half of the country there was not very much near the Canadian boundary, and farther south none of consequence in the majority of districts where snow is anticipated. Near the Ohio River, along Lake Erie, and from eastern Pennsylvania to southern New England several stations reported no measurable snowfall, and most others found the December total the least of record.

In the middle and northern Plains there was moderate snowfall but usually less than normal except in South Dakota.

In the far West the snowfall at elevated stations was generally much greater than normal, several stations finding it the snowiest December for 10 years or longer. The supply remaining at the end of December in areas where storage toward the stream flow of next summer is important was very satisfactory in most of the States which lie west of the Continental Divide, and in considerable portions of New Mexico and Colorado also.

SUNSHINE AND RELATIVE HUMIDITY

More than the usual amount of sunshine for December prevailed generally in the Southeast, while in the far Southwest less than the average was received. Elsewhere about the normal amount prevailed. The relative humidity was generally above normal except in much of the Northeast, portions of the northern Rocky Mountain region, and the northern Pacific Coast States. However, almost everywhere the departures from the normal were small.

SEVERE LOCAL STORMS, DECEMBER, 1931

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Shelby County, Tenn.	6-13				$100,000	Rain and flood	Chief damage to roads	Official, U.S. Weather Bureau.
Block Island, R. I.	7	2:50-3:20 p. m.		3		Wind squall	Sloop and crew lost; steamboat disabled	Do.
South Carolina (western)	8-9					Glaze	Wires and trees broken; communication services impaired considerably.	Do.
Mississippi (delta counties).	8-24					Rain and floods	60,000 acres affected	Do.
Texarkana (near), Tex.	11	2 a. m.	200	2	10,000	Tornado	Several buildings damaged or destroyed; 9 persons injured.	Do.
Hortman (near), La.	13	1:35 a. m.	50-500	2	8,700	do.	Buildings, crops, and timber damaged; path 3 miles long.	Do.
Columbia and Ouachita Counties, Ark.	13	A. m.		1		Tornado and downpour.	Scores of buildings wrecked, chiefly at Waldo, Stephens, and Camden; bridges and embankments washed out; 15 injured.	Post (Washington, D. C.).
Owings Mills and Rockville, Md.	14	P. m.		2		Wind	Trees and poles blown down; minor damage to other property.	Official, U.S. Weather Bureau.
Eureka, Calif., and vicinity.	17					do.	Considerable damage to telephone, telegraph, power lines, and buildings.	Do.
Simpson County, Miss.	30	P. m.		5	50,000	Probably tornado.	50 persons injured; character of damage not reported.	Do.
Auburn (near), Ala.	30-31					Wind	Several buildings destroyed; trees uprooted	Do.
Roberson Springs (near), Ala.	30-31			4	4,000	Tornado	Several homes demolished; path 10 miles long	Do.
Montgomery, Ala.	31	2-4 a. m.				Wind	Large windows broken; many telephones put out of order.	Do.
Gadsden and adjacent counties, Fla.	31				10,000	Winds	Several large tobacco barns razed; buildings unroofed; slats, telephone, telegraph wires, and pine timber damaged; fruit blown off.	Do.
Boone County, Iowa	31					Glaze	750 telephone and telegraph poles blown down; trees broken; highways hazardous.	Do.

RIVERS AND FLOODS

By RICHMOND T. ZOCH

[River and Flood Division, Montrose W. Hayes in charge]

There were numerous overflows during December. However, except in the Tallahatchie and Yazoo Rivers of Mississippi, no flood caused any great damage. In some instances no loss of any kind occurred.

The following is a statement of flood losses:

Tangible property totally or partially destroyed, such as buildings, fences, factories, highways, bridges, railroads, etc.:	
Tombigbee River (Alabama)	$2,500
Grand River (Missouri)	5,000
Green River (Kentucky)	200
Barren River (Kentucky)	1,000
Sulphur River (Texas and Louisiana)	1,100
Total	9,800
Matured crops:	
Tombigbee River	200
Sulphur River	5,000
Total	5,200
Livestock and other movable property:	
Tombigbee River	900
Sulphur River	175
Total	1,075
Suspension of business including wages of employees:	
Tombigbee River	5,500
Sulphur River	1,200
Total	6,700

A report of the losses caused by the floods in the Black, Ouachita, St. Francis, Tallahatchie, Yazoo, and Atchafalaya Rivers will be given in a later issue of the MONTHLY WEATHER REVIEW.

The final report on the flood in the Des Moines River during November gives the loss as $10,000, all of which was to unhoused crops.

The estimated money value of property saved by warnings was as follows:

Tombigbee River	$23,000
Green River	500
Barren River	10,000
West Fork of White River (Indiana)	1,500
Ohio River	11,000
Sulphur River	14,000
Sabine River (Texas and Louisiana)	10,000
Total	70,000

The accompanying table gives the rivers which reached or exceeded the flood stage during December. In cases where the flood continued into January the crest given is the highest stage reached during December and may or may not be the actual crest for the entire flood.

Table of flood stages in December, 1931

River and station	Flood stage	Above flood stages—dates From—	To—	Crest Stage	Date
ATLANTIC SLOPE DRAINAGE	*Feet*			*Feet*	
Chenango: Sherburne, N. Y	8	15	15	8.2	15
Saluda:					
Pelzer, S. C	7	3	5	8.2	4
		8	10	7.2	10
		14	15	8.2	15
		21	22	7.6	22
Chappells, S. C	14	5	7	16.8	6
Broad: Blairs, S. C	15	4	5	17.5	5
		14	15	15.3	15
ATLANTIC SLOPE DRAINAGE—con.					
Santee:					
Rimini, S. C	12	8	10	13.0	10
		16	22	13.7	19
		25	26	12.9	26
Ferguson, S. C	12	11	14	12.1	13
		18	28	12.7	22
Broad: Carlton, Ga	15	5	5	15.8	5
Savannah: Ellenton, S. C	14	7	29	18.6	26
EAST GULF OF MEXICO DRAINAGE					
Oostanaula: Resaca, Ga	22	15	17	23.3	16
Tombigbee:					
Aberdeen, Miss	34	15	20	39.6	16
Columbus, Miss	25	19	21	26.7	20
Lock 4, Demopolis, Ala	39	20	(1)	47.7	26
Pearl: Jackson, Miss	20	18	(1)	23.6	27
West Pearl: Pearl River, La	13	21	(1)	14.2	26
MISSISSIPPI SYSTEM					
Upper Mississippi Basin					
Illinois:					
Havana, Ill	14	Nov. 29	4	14.1	1-2
Peru, Ill	14	Nov. 22	7	17.5	Nov. 24
		13	20	14.7	15
Missouri Basin					
Grand:					
Gallatin, Mo	20	12	12	21.5	12
Chillicothe, Mo	18	12	13	21.2	12
Brunswick, Mo	12	Nov. 18	1	18.9	Nov. 27
Missouri: St. Charles, Mo	25	Nov. 29	1	26.1	Nov. 30
Ohio Basin					
Walhonding: Walhonding, Ohio	8	14	14	10.2	14
Scioto:					
Circleville, Ohio	10	13	15	13.3	15
Chillicothe, Ohio	16	16	16	16.0	16
Barren: Bowling Green, Ky	20	14	15	21.9	15
Green:					
Lock 6, Brownsville, Ky	28	15	15	30.3	15
Lock 4, Woodbury, Ky	33	14	18	38.5	16
Lock 2, Rumsey, Ky	34	18	20	34.8	19
West Fork of White:					
Elliston, Ind	19	13	16	22.0	14
Edwardsport, Ind	15	13	19	18.1	17
East Fork of White: Seymour, Ind	10	14	15	11.5	14
Elk: Fayetteville, Tenn	14	24	24	14.3	24
Ohio:					
Shawneetown, Ill	33	19	22	33.6	21
Dam 50, Fords Ferry, Ky	32	19	24	33.9	21
White Basin					
Black: Black Rock, Ark	14	31	(1)	14.3	31
Red Basin					
Sulphur:					
Ringo Crossing, Tex	20	17	19	24.2	18
Finley, Tex	24	22	26	25.5	23
Lower Mississippi Basin					
St. Francis:					
Chaonia, Mo	22	31	(1)	23.5	31
Fisk, Mo	20	31	(1)	20.0	31
Tallahatchie: Swan Lake, Miss	24	15	(1)	33.9	31
Yazoo:					
Greenwood, Miss	35	23	(1)	36.0	26
Yazoo City, Miss	23	31	(1)	23.2	31
Ouachita:					
Arkadelphia, Ark	12	14	14	17.3	14
		18	19	14.1	18
Camden, Ark	30	18	26	34.9	22
Monroe, La	40	25	(1)	41.3	31
Atchafalaya Basin					
Atchafalaya: Atchafalaya, La	22	27	(1)	22.4	30-31
WEST GULF OF MEXICO DRAINAGE					
Sabine: Logansport, La	25	18	27	27.8	22
PACIFIC SLOPE DRAINAGE					
San Joaquin Basin					
Kings: Piedra, Calif	12	28	28	14.7	28
Columbia Basin					
Coast Fork: Saginaw, Oreg	9	31	31	10.0	31
Long Tom: Monroe, Oreg	10	21	(1)	13.0	28
Willamette: Harrisburg, Oreg	10	31	31	10.0	31

[1] Continued into January, 1932.

All dates in December unless otherwise indicated.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

[By the Marine Division, W. F. McDONALD in Charge]

NORTH ATLANTIC OCEAN

By W. F. McDONALD

The pressure situation.—The average barometric pressure for December, 1931, indicated in general a weakening of the usual Icelandic LOW, which occurred during the middle and latter part of the month. For the month as a whole the barometer averaged one-third of an inch above normal on the Irish coast, with excess pressures in lesser amounts at all stations representing the northeastern Atlantic area. (See Table 1.) Pressure departures were slightly below normal over the northwestern Atlantic, central over the Canadian Maritime Provinces, where storms were most numerous and quite persistent. Normal pressures prevailed in mid-Atlantic and over the West Indies.

The Atlantic HIGH was well developed at the opening of the month, dominating the whole ocean between the American and European coasts south of latitude 45°. About the end of the first week, however, the continuity of this HIGH was broken by the southward extension of a deep LOW over Newfoundland, and high pressure attained full transoceanic development thereafter in only one or two brief spells. High pressure was remarkably persistent over western Europe and also during much of the month, between the Azores and the European coast. A severe cold wave was reported from western Europe about the 20th.

Cyclones and gales.—Storminess was more pronounced over the western than over the eastern portion of the Atlantic, but the month did not rank as an unusually stormy December. The total number of gales reported from ship routes was rather less than usual for the month, although whole gales or stronger were encountered at some place on the northern routes on about two-thirds of the days in the month, but in most cases the gales occurred west of longitude 30°. Within the last 10 days, gale conditions were reported far southward over the western Atlantic as a result of the development of several slow-moving LOWS which combined to form a persistent cyclonic storm central near Newfoundland but extending its influence at times well southward past Bermuda.

The highest winds of the month in no case exceeded force 11, although gales of that severity were reported by four ships, all westbound from north European ports, the German steamship *Dresden* and the American steamship *West Harcuvar* on the 5th, the American steamship *Ensley City* on the 15th, and the American steamship *Seattle Spirit*, on the 16th, as shown in the table of selected storm reports which accompanies this summary.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, December, 1931*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	Inch	Inches		Inches	
Reykjavik, Iceland [1]	29.55	+0.08	30.26	29	28.73	8
Lerwick, Shetland Islands [1]	29.88	+0.16	30.61	21	28.66	4
Valencia, Ireland [1]	30.27	+0.33	30.62	12	29.46	3
Lisbon, Portugal [1]	30.27	+0.16	30.50	4	29.89	30
Madeira [1]	30.12	+0.03	30.37	21	29.81	29
Horta, Azores [1]	30.15	+0.01	30.48	8	29.67	15
Belle Isle, Newfoundland [1]	29.69	−0.01	30.16	6	29.04	28
Halifax, Nova Scotia [1]	29.86	−0.09	30.44	[3] 9	29.38	15
Nantucket [2]	30.03	−0.02	30.61	8	29.50	22
Hatteras [2]	30.16	+0.03	30.57	8	29.85	4
Bermuda [1]	30.15	+0.03	30.40	4	29.78	29
Turks Island [1]	30.12	+0.00	30.20	[3] 13	30.02	29
Key West [2]	30.07	−0.01	30.18	19	29.80	31
New Orleans [2]	30.07	−0.06	30.40	15	29.61	30
Cape Gracias, Nicaragua [1]	29.90	−0.08	29.96	[3] 25	29.84	[3] 11

[1] All data based on a. m. observations only, with departures compiled from best available normals related to time of observations.
[2] Corrected 24-hour means, based on more than one observation daily.
[3] And other date or dates.

Charts VIII to XI cover selected days in December, to illustrate the stormier portions of the month on the North Atlantic.

Unusually heavy seas accompanying the storm of December 16th (shown on Chart IX) were reported in news dispatches to have made navigation exceedingly difficult for the eastbound Anchor liner *Tuscania*, which was forced on several occasions to come about to face the sea, and was once overwhelmed by a huge following wave that caused the death of one passenger and injured a number of others on deck at the time.

Fog.—Fog was mostly confined to the region of the Grand Banks and the New England coast, being reported in one or more localities on about half the dates in the month, but in no single 5-degree square on more than four days. Six dates with fog were reported from coastal waters of the northwestern Gulf of Mexico.

OCEAN GALES AND STORMS, DECEMBER, 1931

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Grete, Ger. S. S.	Hamburg	New York	50 12 N	27 30 W	Dec. 1	3 p, 1	Dec. 2	28.98	SSE	SSW, 8	WNW	—, 10	SSE-SW.
Examelia, Am. S. S.	Lisbon	do	43 00 N	35 58 W	Nov. 30	1 a, 1	do	29.70	S	W, 9	S	S, 10	S-SW-W.
West Harcuvar, Am. S. S.	Hamburg	Boston	50 20 N	26 09 W	Dec. 1	Noon, 2	do	29.36	SW	WSW, 7	W	WSW, 10	WSW-W.
Titus, Du. S. S.	Port Barrios	Amsterdam	41 37 N	48 40 W	Dec. 2	4.30 p, 2	do	29.28	SSE	N, 10	NNE	—, 10	SSE-S-W-N.
Winnebago, Br. S. S.	New York	Avonmouth	48 32 N	30 40 W	Dec. 3	Mdt, 3	Dec. 5	29.23	SSE	WSW, 9	SW	WNW, 10	SSE-WSW.
Polybius, Am. S. S.	Manchester	Beaumont, Tex.	53 27 N	4 38 W	Dec. 2	Noon, 3	Dec. 7	29.28	S	SW, 10	NW	W, 10	S-W.
Otho, Am. S. S.	St. Vincent	New York	37 30 N	65 30 W	Dec. 4	6 p, 4	Dec. 5	29.68	SW	SW, 6	NW	SW, 10	SW-W-NW.
Dresden, Ger. S. S.	Cobh	do	44 00 N	55 18 W	Dec. 5	3 p, 5	Dec. 8	29.02	SSW	SSW, —	NNW	NNW, 11	SSW-WNW.
West Harcuvar, Am. S. S.	Hamburg	Boston	48 56 N	40 12 W	do	11 p, 5	Dec. 7	29.20	WSW	S, 6	S	WSW, 11	S-WSW.
Missouri, Br. S. S.	London	New York	47 44 N	33 58 W	Dec. 6	5 p, 6	do	29.59	S	SW, 9	WSW	SW, 9	SW-WSW.
Cerinthus, Br. S. S.	Port Arthur	Antwerp	47 26 N	10 03 W	do	Noon, 6	do	29.68	NW	WNW, 5	N	NNW, 9	
Aden Maru, Jap. S. S.	Fowey	Portland, Me.	43 26 N	60 37 W	Dec. 7	3 p, 7	do	29.29	W	W, 8	W	W, 10	W-WNW-W.
Tiger, Nor. S. S.	Harstad, Norway.	Baton Rouge	61 58 N	20 15 W	do	10 a, 7	do	28.96	SSE	SE, 10	SW	—, 10	SE-SW.
Examelia, Am. S. S.	Lisbon	New York	41 50 N	58 32 W	do	6 a, 8	Dec. 9	29.43	S	WNW, 7	N	—, 10	WNW-W-NW.

Ocean gales and storms, December, 1931—Continued

Vessel	Voyage: From—	Voyage: To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN—Con.			° ′	° ′				*Inches*					
Persephone, Danzig M. S.	Florida Straits.	Rotterdam	34 58 N	52 50 W	Dec. 7	3 p, 8	Dec. 10	29.77	S	WNW, 8	N	NNW, 10	WNW-NW.
Berlin, Ger. S. S.	Bremerhaven	New York	47 43 N	37 30 W	Dec. 8	1 p, 9	Dec. 9	29.20	SW	SSW, 9	SW	S, 9	SSW-NW.
Coahoma County, Am. S. S.	Antwerp	do	49 02 N	28 53 W	Dec. 6	3 p, 10	Dec. 10	29.68	NW	S, 10	NNE	S, 10	S-SSW-N.
Shickshinny, Am. S. S.	Manchester	Charleston	44 35 N	24 30 W	Dec. 11	8 a, 11	Dec. 12	29.91	SE	SE, 7	SE	—, 10	Steady.
Venezuela, Du. S. S.	Europe	Barbados	36 26 N	27 47 W	Dec. 10	5 a, 11	Dec. 11	29.76	SE	SE, 9	WSW	SE, 9	SE-SW.
Cripple Creek, Am. S. S.	Manchester	New Orleans	44 52 N	36 02 W	Dec. 11	10 a, 14	Dec. 16	28.89	SSE	SSW, 7	SW	W, 10	W-WNW.
Ensley City, Am. S. S.	Liverpool	Baltimore	45 50 N	47 05 W	Dec. 15	8 p, 15	Dec. 19	29.02	S	WSW, 8	W	W, 11	S-SW-NW.
Cold Harbor, Am. S. S.	Cork	Boston	47 45 N	49 30 W	Dec. 13	1 a, 16	Dec. 16	28.80	S	WSW, 10	NW	WSW, 10	SW-WSW.
Seattle Spirit, Am. S. S.	Nordenham	do	50 09 N	32 16 W	Dec. 16	—, 16	Dec. 18	29.38	S	S, 8	W	—, 11	
Exton, Am. S. S.	New York	Malta	39 56 N	61 15 W	Dec. 17	10 a, 18	do	29.87	W	WNW, 9	NW	WNW, 9	W-NW.
Maine, Dan. S. S.	Antwerp	Providence	41 30 N	58 49 W	Dec. 18	4 a, 18	do	29.61	WNW		NNW	—, 10	Steady.
Volendam, Du. S. S.	Rotterdam	New York	48 33 N	44 32 W	Dec. 15	3 a, 18	do	28.97	SE	NW, 10	W	NW, 10	SW-NW.
Kenbane, Br. S. S.	Fowey	Boston	49 07 N	37 20 W	Dec. 16	2 p, 19	Dec. 19	29.20	SSW	SW, 8	WSW	S, 10	SSE-WSW.
Exilona, Am. S. S.	Casa Blanca	do	41 09 N	57 24 W	Dec. 18	1 a, 20	Dec. 20	29.54	SW	NW, 7	NW	W, 10	NW-N-NE.
Independence Hall, Am. S. S.	Bordeaux	New York	35 00 N	58 00 W	Dec. 21	6 a, 21	Dec. 21	29.65	S	S, 9	N	—, 10	S-W-N.
Tiberius, Du. S. S.	English Channel.	San Juan	32 50 N	43 58 W	Dec. 22	3 p, 22	Dec. 22	29.40	SW	SW, 9	N	NNW, 9	
Poseidon, Du. S. S.	Port Barrios	Amsterdam	34 15 N	74 10 W	Dec. 25	5 a, 25	Dec. 28	29.85	NW	NW, 8	NW	—, 9	SW-NW.
Exeter, Am. S. S.	Marseille	New York	36 36 N	52 52 W	Dec. 26	11 a, 27	do	29.31	SW	SW, 10	NW	SW, 10	SW-WNW.
Trimountain, Am. S. S.	Manchester	Jacksonville	38 23 N	40 00 W	Dec. 28	2 p, 28	Dec. 29	29.69	ESE	S, 8	NW	SW, 9	SW-W-NNW.
Poseidon, Du. S. S.	Port Barrios	Amsterdam	37 50 N	52 30 W	Dec. 29	Mdt, 29	Dec. 30	29.46	SW	SW, 9	SE	SSW, 10	
City of Alton, Am. S. S.	Rotterdam	New York	43 46 N	50 02 W	Dec. 30	Noon, 30	do	29.01	SW	SW, 7	NW	NW, 10	SW-NW.
NORTH PACIFIC OCEAN													
Oregon, Am. S. S.	Otaru	San Francisco.	46 30 N	143 15 W	Dec. 1	1 a, 1	Dec. 2	29.60	NW	NW, 11	WNW	NW, 11	
Grays Harbor, Am. S. S.	Taku Bar	Seattle	46 52 N	165 53 E	do	Noon, 2	do	29.04	SSW	S, 12	W	S, 12	S-W.
Shelton, Am. S. S.	Hong Kong	San Francisco.	41 55 N	159 00 E	do	4 a, 2	do	29.31	S	WNW, 6	SW	S, 10	
Tacoma, Am. S. S.	Tacoma	Yokohama	49 50 N	174 15 E	Dec. 2		do	29.22	S	S, 11	SSW	S, 11	SSE-SSW.
Forthbank, Br. S. S.	Balboa	Kobe	26 46 N	157 50 W	Dec. 3	6 p, 3	Dec. 5	29.85	N	N, 9	NNE	N, 9	Steady.
Grays Harbor, Am. S. S.	Taku Bar	Seattle	49 19 N	177 35 W	Dec. 4	1 p, 4	Dec. 4	29.49	S	S, 10	NW	S, 10	S-W.
Shelton, Am. S. S.	Hong Kong	San Francisco.	45 35 N	173 02 E	do	3 a, 5	Dec. 5	29.44	SSE	S, 9	S	S, 10	SSE-S-NW.
Golden Sun, Am. S. S.	Dairen	do	37 28 N	151 30 W	do	2 p, 5	do	29.69	N	N, 10	ENE	N, 10	N-NE.
Emp. of Japan, Br. S. S.	Vancouver	Honolulu	45 50 N	130 05 W	Dec. 6	Noon, 6	Dec. 6	29.06	SE	N, 7	NW	NW, 12	SSW-W-NW.
Emma Alexander, Am. S. S.	San Diego	Seattle	47 04 N	124 54 W	do	8 p, 6	Dec. 7	29.16	ESE	S, 8	SSW	SW, 9	SSE-S-SW.
San Pedro Maru, Jap. M. S.	Kobe	San Francisco.	41 12 N	156 10 E	Dec. 7	4 p, 8	Dec. 9	29.38	SSW	NW, 8	WNW	NW, 10	W-NW-WNW.
Soyo Maru, Jap. M. S.	San Francisco.	Yokohama	44 05 N	163 43 E	Dec. 9	4 a, 9	Dec. 13	29.02	W	W, 8	SSE	WNW, 10	W-WNW.
Forthbank, Br. S. S.	Balboa	Kobe	29 37 N	172 45 E	Dec. 10	4 p, 10	Dec. 11	29.96	NE	NE, 9	NE	NE, 9	NE-N.
Pres. Hayes, Am. S. S.	Honolulu	do	26 23 N	171 52 E	do	6 p, 10	do	29.32	NW	N, 9	NNW	N, 10	Steady.
Nevada, Am. S. S.	Columbia River.	Yokohama	52 30 N	173 55 W	Dec. 11	2 p, 11	Dec. 13	29.53	SE	WSW, 4	W	W, 10	SSE-WSW.
Pres. Lincoln, Am. S. S.	Honolulu	San Francisco.	26 05 N	149 58 W	do	Mdt, 11	do	29.67	SE	SE, 7	E	E, 9	
Makawao, Am. S. S.	San Francisco.	Honolulu	32 19 N	137 00 W	Dec. 14	9 p, 14	Dec. 15	29.58	SE	SE, 9	SE	SE, 9	
Texas, Am. S. S.	Lamit Bay, P. I.	San Francisco.	39 33 N	155 25 W	do	Noon, 15	do	29.91	NNW	N, 7	N	N, 9	Steady.
Emma Alexander, Am. S. S.	Seattle	San Diego	48 00 N	124 52 W	Dec. 16	—, 17	Dec. 17	29.64	SE	S, 6	S	S, 10	SE-S.
Matsonia, Am. S. S.	San Francisco.	Honolulu	35 37 N	129 44 W	Dec. 17	3 p, 17	do	29.56	SSE	SSW, 9	WSW	SSW, 9	SSE-S-SSW.
Heian Maru, Jap. M. S.	Yokohama	Vancouver	50 34 N	151 43 W	Dec. 16	8 a, 18	Dec. 18	29.59	NW	NNW, 7		—, 10	N-NW.
Fernwood, Nor. M. S.	San Pedro	Yokohama	37 27 N	161 45 E	do	3 p, 18	do	29.87	S	NW, 11	NW	NW, 11	SE-NW.
Admiral Peoples, Am. S. S.	Portland	Wilmington	Off Cape Blanco Light.		do	6 a, 17	do	29.66	SSE	S, 6	SW	S, 11	S-SSE.
Northwestern, Am. S. S.	Seattle	Seward	60 14 N	146 40 W	Dec. 17	9 p, 17	do	29.28	NE	NE, 7	NW	NE, 9	NE-NW.
Melmay, Br. S. S.	Karatsu	New Westminster.	51 02 N	163 56 W	Dec. 19	4 p, 19	Dec. 21	[1] 29.59	S	S, 8	NW	WNW, 9	
Emma Alexander, Am. S. S.	Seattle	San Diego	43 15 N	124 42 W	Dec. 21	Noon, 21	do	29.44	SSE	SSE, 9	SW	SSE, 9	SSE-SW.
Yoseric, Br. S. S.	Koseir	Osaka	16 40 N	116 42 E	Dec. 20	4 p, 20	Dec. 25	29.99	NNE	NE, 8	NE	NE, 9	NNE-NE.
Mala, Am. S. S.	Puget Sound	Hawaiian Is	43 28 N	133 00 W	Dec. 22	—, 23	Dec. 23	29.02	SW	SW, 10	WNW	SW, 10	SW-W.
Canadian Ranger, Can. S. S.	Balboa	Vancouver	45 10 N	125 04 W	do	2 p, 23	Dec. 24	29.17	S	S, 10	SSW	S, 10	S-SSW.
Emma Alexander, Am. S. S.	Seattle	San Diego	Off San Francisco		Dec. 23	4 p, 23	do	29.89	SSW	SSW, 6	SE	SE, 10	SSW-SE.
City of Elwood, Am. M. S.	Shanghai	San Pedro	37 18 N	146 15 W	Dec. 24	6 p, 25	Dec. 26	29.73	WSW	W, 9	NW	W, 9	WSW-W-NW.
Bellingham, Am. S. S.	Tacoma	Yokohama	35 59 N	141 58 E	Dec. 25	Noon, 25	do	29.50	NNE	NNE, 10	NNE	NNE, 10	Steady.
Mala, Am. S. S.	Puget Sound	Hawaiian Is	40 22 N	137 02 W	do	—, 25	do	29.22	SW	SW, 9	W	W, 11	W-NW.
Mojave, Am. S. S.	Seattle	San Pedro	43 40 N	124 55 W	do	3 a, 26	do	29.31	S	SSE, 10	SSE	SSE, 11	SSE-SW.
Takaoka Maru, Jap. S. S.	Yokohama	San Francisco.	35 25 N	145 50 E	do	9 p, 25	Dec. 27	[1] 29.65	N	N, 8	N	N, 10	Steady.
Melmay, Br. S. S.	Karatsu	New Westminster.	50 00 N	131 00 W	do	4 p, 26	do	[1] 28.95	SE	SSE, 10	SW	ESE, 11	
Adm. Farragut, Am. S. S.	Portland	San Francisco.	37 00 N	122 20 W	Dec. 26	3 a, 27	do	29.94	S	S, 9	SE	SE, 10	S-SE-S.
Olympia, Am. S. S.	Manila	do	36 30 N	154 02 E	Dec. 27	1 a, 27	do	[1] 29.45	N	N, 8	NW	N, 9	N-NNW.
Takaoka Maru, Jap. S. S.	Yokohama	do	39 35 N	155 24 E	Dec. 28	Noon, 29	Dec. 31	29.35	S	W, 11	N	W, 11	
Everett, Am. S. S.	Dairen	Seattle	49 46 N	176 45 E	do	2 p, 30	do	28.20	NNW	SW, 9	W	W, 11	S-SW-W.
Brandywine, Am. S. S.	Seattle	San Pedro	42 12 N	125 02 W	Dec. 29	2 p, 29	Dec. 30	[1] 29.84	SSE	SSE, —	SE	SE, 9	SSE-SE.
Hakonesan Maru, Jap. M. S.	Yokohama	San Francisco.	42 30 N	172 51 E	do	2 a, 30	do	29.08	SE	S, 11	W	S, 11	SSE-S-SSW.
Hikawa Maru, Jap. M. S.	do	Vancouver	49 00 N	179 30 W	do	6 p, 30	Dec. 31	28.67	SSE	SW, 9	W	WSW, 10	
Emp. of Russia, Can. S. S.	do	do	46 20 N	167 00 E	do	5 a, 30	do	28.41	S	WSW, 6	WNW	W, 11	WSW-WNW.

[1] Barometer uncorrected.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Atmospheric pressure.—The average pressure distribution for December, 1931, showed an elongated region of low barometer stretching in upper latitudes from the American coast far into the Bering Sea, with centers near St. Paul Island and in the Gulf of Alaska. At Dutch Harbor, near the usual center of action of the Aleutian LOW, the average pressure of 29.72 inches was almost two-tenths of an inch higher than that at St. Paul, which is a very unusual condition. In the Gulf of Alaska the LOW was maintained rather vigorously from the 13th until the close of the month and, because, for much of that period, it extended far southward, average pressures along the American coast were well below the normal almost to extreme southern California.

In consequence of the extensive cyclonic developments over the eastern part of the Pacific, the main body of the great North Pacific anticyclone was crested near midocean at about the thirtieth parallel, with a minor anticyclone prevailing for the greater part of the month west of southern and Lower California. In the Far East fewer cyclones than normal for December entered the sea from the continent, and an extensive bank of high pressure for the most part overlay eastern Asia and, in lesser degree, the Japanese Archipelago. The principal cyclones of the western waters of the Pacific seem to have originated over the Kuro Siwo Current.

The following table gives barometric data for several island and coast stations in west longitudes, including Point Barrow on the Arctic Ocean.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure, at sea level, North Pacific Ocean and adjacent waters, December, 1931, at selected stations*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow [1] [2]	29.87	−0.16	30.56	31st	29.26	22d.[3]
Dutch Harbor [1]	29.72	+0.16	30.34	6th	29.00	1st.
St. Paul [1] [2]	29.53	−0.05	30.40	14th	28.36	7th.
Kodiak [1]	29.51	−0.05	30.20	10th	28.88	17th.
Midway Island [1]	30.18	+0.17	30.42	20th	29.76	12th.
Honolulu [4]	30.01	0.00	30.24	20th	29.70	12th.
Juneau [4]	29.60	−0.19	30.14	10th	28.67	16th.
Tatoosh Island [4] [5]	29.78	−0.18	30.42	5th	29.06	23d.
San Francisco [4] [5]	30.04	−0.08	30.37	16th	29.63	28th.
San Diego [4] [5]	30.07	0.00	30.32	26th	29.72	9th.

[1] P. m. observations in averages; a. m. and p. m. in extremes.
[2] For 30 days.
[3] And on the 23d.,
[4] A. m. and p. m. observations.
[5] Corrected to 24-hour mean.

Cyclones and gales.—Following hard upon the stormy weather of November, 1931, that of December was equally disturbed in northern and western waters, but far stormier off our American west coast. Here, on the 6th and 7th and from the 17th until the 29th, the coastal region was swept by intermittent gales that extended as far southward on the 23d and 27th as the latitude of San Francisco. The cyclone causing the gales of the 6th and 7th developed rather suddenly west of Vancouver Island and within a few hours had acquired its greatest intensity, with central pressure below 29.40 inches. The gales blew over the region between the coast and the one hundred and thirty-fifth meridian and for a time attained hurricane force near 46° N., 130° W.

The succeeding coastal gales occurred on the southeastern boundary region of the elongated cyclone, the central area of which lay over the Gulf of Alaska from the 13th to 31st. Coastwise steamers during this period encountered the most intense gales—of force 11 from southerly directions—on the 17th and 26th, south of North Head, Wash., and from westerly directions of similar force on the 26th west of Vancouver and near 40° N., 137° W. On the 23d and 27th whole gales (force 10) were reported off the central California coast, and fresh to strong gales over a long stretch of coast on other dates. Several vessels on the 26th were forced to heave to for hours in the violent storm.

Midway along the upper routes between the American coast and the Aleutian Islands gales were less frequent than elsewhere in the same latitudes. The greater part of the high winds occurred after the middle of the month here, but the highest reported velocity was on the 1st, when a northwest gale of force 11 was experienced near 46° N., 143° W. South of Dutch Harbor maximum forces of 11 to 12 occurred on the 22d and 28th. Between 170° W. and Japan, over a wide strip of ocean south of the fiftieth parallel stormy weather was frequent and severe. South and southwest of the western Aleutians winds of the higher forces, 11 to 12, were reported on the 2d, 18th, 29th, and 30th, in addition to those of lesser forces, 8 to 10, on many other days. The storm to hurricane forces of the 2d, 29th, and 30th were felt over a wide range of the sea.

Special mention should be made of a rather interesting disturbance which developed east of the Hawaiian Islands on the 6th. For upward of a week it remained practically stationary, its northward advance blocked by a middle-latitude anticyclone. By the 10th and 11th fresh to strong easterly gales were blowing on its north sector, in 27° to 29° N., 145° to 150° W. On the 14th, however, the HIGH gave way and the disturbance, accompanied by gales of force 8 to 9, quickly escaped to higher latitudes, where it joined with the cyclone then stretching southward from Alaskan waters.

Only one tropical disturbance of any intensity, and that of slight extent, occurred in December, 1931. This was a typhoon of the central Philippines and is described in the subjoined article by the Rev. Miguel Selga, S. J., director of the Philippine Weather Bureau.

Other moderately stormy weather in various parts of the Tropics was occasioned by strong northeast monsoons which rose to gale force on several days in the China Sea. On the 4th of the month trade winds of force 8 occurred west of the Hawaiian Islands, and on the 15th, 26th, and 27th northers of moderate gale force were experienced in the Gulf of Tehuantepec.

Winds at Honolulu.—The prevailing wind direction at Honolulu was from the east. The maximum velocity was 43 miles from the east on the 20th, during the prevalence of a very strong anticyclone to the northward.

Fog.—The occurrence of fog in December increased slightly over that of November along the northern routes, and decreased slightly in American coastal waters. Fog was reported on seven days along the length of coast between Eureka and San Diego, and on not to exceed three days in the foggiest of 5° squares in higher latitudes of the open Pacific. As a rule its occurrence was widely scattered, but on the 5th to 7th it was more evenly distributed.

THE TYPHOON OF VISAYAS, DECEMBER 5-6, 1931

By Rev. MIGUEL SELGA, S. J.

[Weather Bureau, Manila, P. I.]

The afternoon weather map of December 4, 1931, shows an area of low pressure extending over southern Visayas, Mindanao, and Palawan. The rapid drop of the barometer east of Samar early in the morning of December 5, left no doubt but that a typhoon had developed in the eastern sector of the depression and it was fast approaching Samar. Typhoon warnings were sent immediately to all the Provinces and stations likely to be affected, and, on account of the peculiar period of the milling season, to all the sugar centrals of Visayas. The typhoon moved so fast that shortly after noon of December 5, it passed south of and very close to Catbalogan, Samar, where the barometer dropped from 756.91 mm. at 8 a. m. to 734.67 mm. 18 minutes past noon. Government offices at

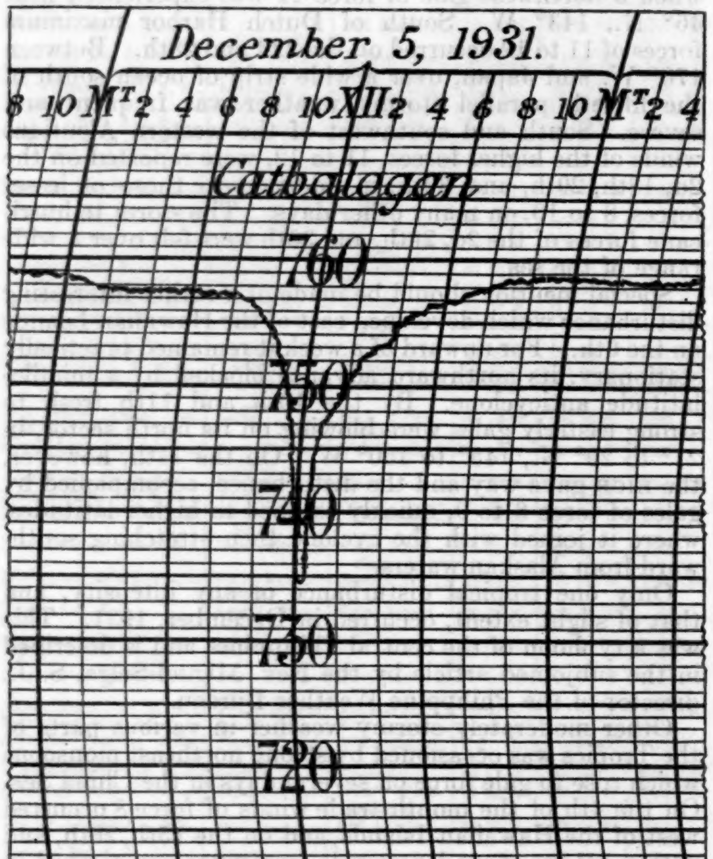


FIGURE 1.—Barogram of the typhoon of December 5, 1931, at Catbalogan, west coast of Samar

Catbalogan were closed at 11 a. m. and the employees sent home to prepare for the storm. The quick dissemination of typhoon warnings by means of the police and the town crier minimized the damages that otherwise would have taken place, yet 28 fish corrals were reported destroyed, over a hundred houses of light materials were damaged, and two persons were found drowned in the barrios of Catbalogan. Taking a west by northwest direction, the typhoon passed north of Capiz at 7 p. m. causing a barometric minimum of 744.66 mm. and southwesterly gusts of force 11. One hour and a half after midnight, the typhoon passed close to and north of the Culion Leper Colony and was located in the China Sea about 130 miles to the westward on the morning weather map of December 6.

The typhoon was treacherous on account of the high velocity of its translation and the narrowness of its diameter. The 530 kilometers that separated Catbalogan from Culion were covered by the typhoon in 13 hours and 15 minutes, giving a velocity of 40 kilometers, or almost 25 miles, per hour.

The narrowness of the storm's diameter is evident from the fact that, * * * although the wind was very strong in the proximity of the center, yet in some places like Culion and southern Mindoro, four hours before and after the barometric minimum the wind was no more than a gentle breeze with clear or partly cloudy sky. The motor boat *Siruma* was washed ashore and completely destroyed on the eastern coast of Sibuyan and the *Virginia*, on the western coast of Busuanga. The barogram from Catbalogan, presented herewith, shows the limited extent, but steepness of gradient, of the typhoon.

BUCKET OBSERVATIONS OF SEA-SURFACE TEMPERATURES

By GILES SLOCUM

STRAITS OF FLORIDA AND CARIBBEAN SEA

Table 1 shows the average temperatures for the Caribbean Sea and the Straits of Florida for December of each year from 1919 to 1930, inclusive, and Table 2 summarizes the temperatures for December, 1930, in the same areas. The chart shows the number of observations taken in December, 1930, within each 1° square, and mean temperature data for subdivisions of the area considered.

The surface temperatures of the Straits of Florida fall rapidly during December, but the seasonal downward trend frequently is interrupted by alternations of warmer and cooler quarter-months, especially in the latter part of the month. This fluctuation of mean temperature is a winter condition, and is in contrast with the fairly steady and persistent drop of autumn. By the end of the month, the transition from autumn to winter is well advanced, and normal temperatures characteristic of winter prevail, with the water temperatures usually not far from the normal annual minimum.

During December the season has not progressed so far in the Caribbean, where autumn conditions still persist, as it has in the straits. This month is in the midst of the period of most rapid drop in normal temperature over all parts of the Caribbean Sea, where the winter season of relatively low temperatures, with little or no upward or downward trend, is delayed until late January and lasts until early March.

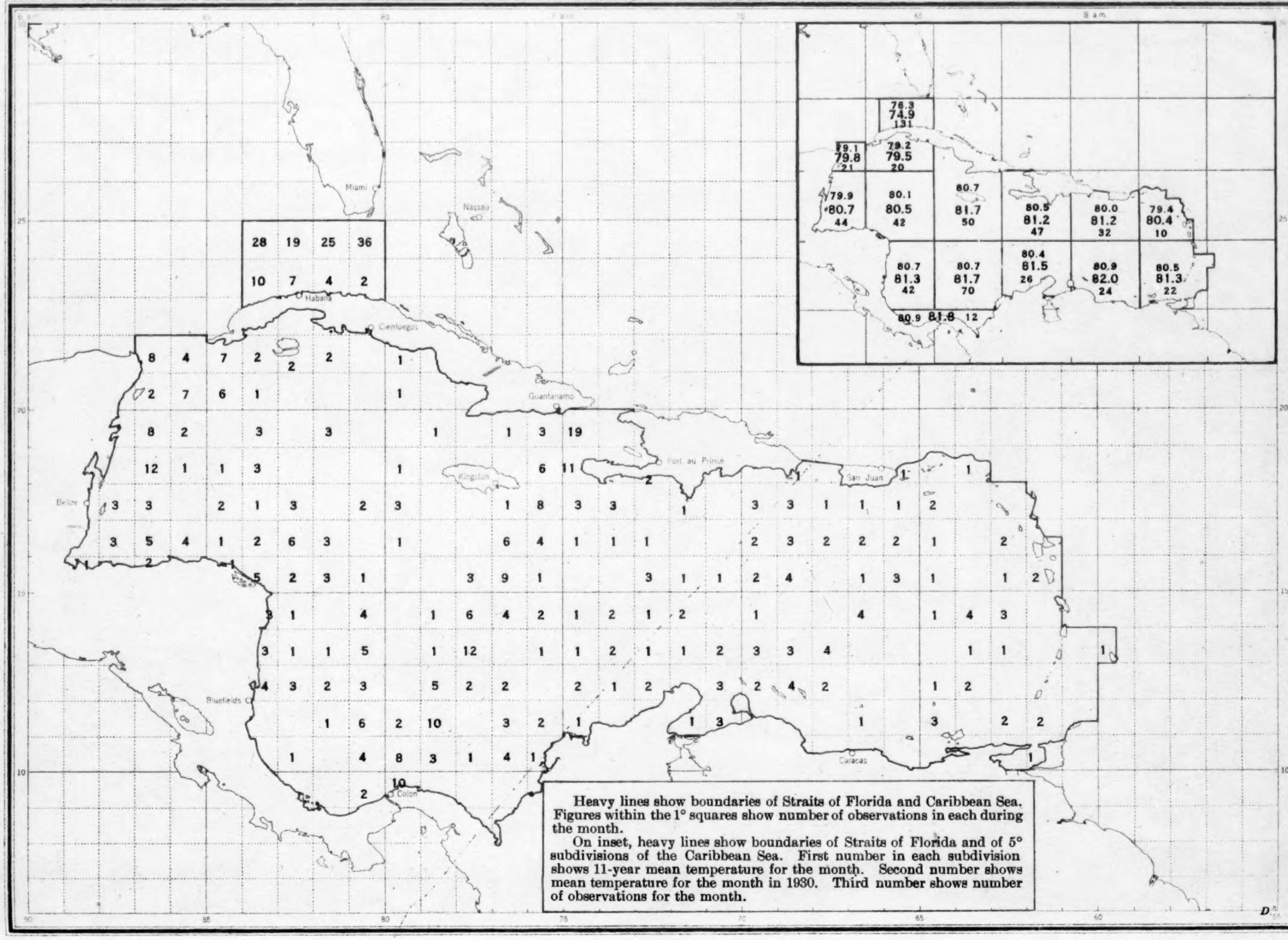
December, 1930, was the warmest December in the Caribbean during the term of years covered (1920–1930), and the coolest in the Straits of Florida. For this month as a whole nearly all parts of the Caribbean were unprecedentedly warm and *all* distinctly above their average temperatures for the 11-year period. The third quarter of this month was relatively the coolest, when the mean temperature of the Caribbean was a trifle below that of the same period in 1926. The other three quarters were record-breaking or record-equaling. In the Straits of Florida, only the first quarter of this month was near the seasonal average. The second, third, and fourth quarters were cooler than the hitherto coolest corresponding periods.

Current charts[1] indicate that the water flowing through the Yucatan Channel between November and January divides into three main branches. The weakest, in the

[1] Cf. Hydrographic Office of the Navy Department of the United States. Pilot Chart of the Central American Waters. Washington, D. C. Published monthly.

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, December, 1930

(Plotted by Giles Slocum)



Heavy lines show boundaries of Straits of Florida and Caribbean Sea. Figures within the 1° squares show number of observations in each during the month.

On inset, heavy lines show boundaries of Straits of Florida and of 5° subdivisions of the Caribbean Sea. First number in each subdivision shows 11-year mean temperature for the month. Second number shows mean temperature for the month in 1930. Third number shows number of observations for the month.

sense of the least rapid, makes, as does the main[2] flow in the summer and autumn months, the circuit of the Gulf, around the Sigsbee Deep. The stronger and principal winter branches take a more direct route to the straits. Here, the currents indicated on the Hydrographic Office Charts[1] show that, during the late autumn and early winter, one branch heads almost due north from the Yucatan Channel, and reaches a point about 200 miles south of Mobile Bay, where it turns sharply to the eastward, then south-southeastward into the straits. A second branch flows almost directly from the channel, around northern Cuba and through the straits, joining the first near Alligator Reef, off the extreme southeast Florida coast. Both these currents seem to be rapid enough to cause that surface water from the Yucatan Channel which takes these routes to start passing through the straits by December. Therefore, it is to be expected that the Caribbean will begin, at this time of the year, to show its maximum effect in warming the waters of the straits.

In view of this geographical distribution of currents the conditions in 1930, when the Caribbean was warm throughout the autumn and the straits extremely cool in December, would seem to indicate one or the other of the following alternatives:

(1) That the currents or the conditions affecting the surface temperatures in these regions were in some way abnormal at that time;

(2) That the variations of the surface temperatures of the Caribbean waters do not soon thereafter and directly correspondingly modify the surface temperatures in the straits.

Considerable evidence, which will be discussed at a later time, favors the first of these two alternatives. Hence we may presume that the surface temperatures which obtained late in 1930 in these regions probably were caused by the superposition of some infrequent (though not unprecedented) control or controls upon the continuous influences of the flow from the Caribbean.

During the year 1930 all months except January and February showed temperatures above the 11-year mean in the Caribbean. A run of 10 consecutive months of high temperatures is, however, not an unusual condition in this area. Records show that periods of above average or below average temperature, are likely to last for from one to three or more years.

[1] Cf. Hydrographic Office of the Navy Department of the United States. Pilot Chart of the Central American Waters. Washington, D. C. Published Monthly.

[2] Cf. Bucket Observations of Sea Surface Temperatures. MONTHLY WEATHER REVIEW. Vol. 59 : 211.

The year 1930 may then be summarized as containing the beginning of a more or less extended period of high temperatures in this area and having one record-breaking month. Notwithstanding the exceedingly high temperature of its final month, this year as a whole was not as warm as some others of the preceding decade, being merely an ordinarily warm year.

The mean temperature for 1930 in the Straits of Florida approximated the 11-year average, but June and December of that year were the coolest of these respective months in the 11-year period considered. The principal positive deviations from average temperatures were in the early part of the year. The departures for the last three months were negative.

TABLE 1.—*Mean sea-surface temperatures in the Caribbean Sea and the Straits of Florida for December, 1919–1930*

Year	Carribbean Sea		Straits of Florida	
	Number of observations	Mean (° F.)	Number of observations	Mean (° F.)
1919 [1]	134	80.2	14	76.4
1920	199	80.4	57	76.1
1921	211	79.8	67	76.7
1922	241	79.9	87	77.3
1923	238	79.6	103	76.0
1924	287	80.2	98	75.9
1925	349	80.8	120	76.6
1926	330	80.9	142	77.0
1927	386	80.5	117	76.5
1928	354	80.3	120	76.4
1929	564	80.1	138	76.5
1930	462	81.2	130	74.9
Mean (1920–1930)		80.3		76.3

[1] Not used in computations because of insufficient data available.

TABLE 2.—*Mean sea-surface temperatures (°F.) and number of observations, December, 1930*

Quarter	Period	Caribbean Sea				Straits of Florida			
		Number of observations	Mean	Departure from 11-year mean (1920–1930)	Change from preceding month	Number of observations	Mean	Departure from 11-year mean (1920–1930)	Change from preceding month
			° F.	° F.	° F.		° F.	° F.	° F.
I	Dec. 1–7	92	81.7			36	76.7		
II	Dec. 8–15	137	81.4			30	74.6		
III	Dec. 16–23	114	80.8			29	75.2		
IV	Dec. 24–31	119	80.8			35	73.0		
	Month	462	81.2	+0.9	−0.8	130	74.9	−1.4	−3.3

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, December, 1931

[For description of tables and charts, see REVIEW, January, p. 50]

Section	Temperature								Precipitation				
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	°F	°F		°F			°F		In.	In.		In.		In.
Alabama	55.8	+8.6	3 stations	83	[1] 10	Riverton	25	[1] 15	8.90	+4.08	Millers Ferry	15.15	Union Springs	3.52
Arizona	40.3	-3.8	Granite Reef Dam	87	20	Fort Defiance	-26	14	1.58	+.32	Supai	4.98	2 stations	.12
Arkansas	48.7	+6.2	Pine Bluff	78	23	Lead Hill	17	15	7.79	+3.70	El Dorado	23.86	Gravette	.52
California	42.4	-2.6	San Jacinto	83	18	South Lake	-22	12	8.48	+4.24	Ben Lomond	30.37	Greenland Ranch	.03
Colorado	23.8	-.9	Las Animas	78	24	Hermit	-40	13	.58	-.42	Cumbres	4.55	7 stations	
Florida	69.8	+10.0	Moore Haven	90	5	Hilliard	36	29	2.96	+.06	Pensacola	8.98	Coral Gables	.08
Georgia	56.8	+9.3	2 stations	86	[1] 1	Clayton	19	27	7.02	+2.75	Dahlonega	17.32	Meldrim	1.09
Idaho	22.2	-2.6	Twin Falls Factory	58	24	Felt	-30	15	2.71	+.51	Deadwood	13.67	Cottonwood	.21
Illinois	39.8	+9.2	New Burnside	76	11	Freeport	7	8	2.95	+.80	Mount Carmel	5.52	Pearl	1.59
Indiana	40.4	+8.3	Princeton	76	11	Notre Dame	11	8	3.40	+.54	Princeton	6.73	Rochester	1.06
Iowa	34.1	+10.0	2 stations	61	18	Lake Park (near)	3	7	2.48	+1.34	Lacona	4.40	Waverly	.81
Kansas	38.9	+7.0	Ashland	75	23	St. Francis	2	15	.65	-.19	Atchison	3.09	Ulysses	.02
Kentucky	46.1	+8.6	2 stations	73	[1] 11	2 stations	17	[1] 2	5.51	+1.48	Burnside	8.12	Ashland	2.94
Louisiana	57.9	+5.8	Morgan City	86	13	Plain Dealing	29	4	10.53	+5.31	Calhoun	26.34	Port Eads	3.59
Maryland-Delaware	42.8	+7.4	La Plata, Md	72	19	Sines, Md	9	8	2.45	-.71	Friendsville, Md	5.04	Hancock (city), Md	1.76
Michigan	32.7	+7.5	Monroe	64	11	Mio	-13	8	2.01	-.07	Lapeer	4.79	Iron River	.41
Minnesota	24.9	+10.4	Morris	59	30	2 stations	-24	[1] 6	.58	-.15	Fairmont	2.48	2 stations	T.
Mississippi	55.6	+7.4	Crystal Springs	87	11	Holly Springs	27	15	11.96	+6.69	Greenville	21.53	Macon	6.93
Missouri	42.7	+8.8	Marble Hill	80	30	Maryville	11	14	2.57	+.50	Caruthersville	9.32	Nevada	.42
Montana	24.4	+2.6	Melstone	67	18	Kinread	-30	12	.62	-.25	Heron	5.79	2 stations	T.
Nebraska	31.2	+5.3	Kimball	66	18	Gordon	-12	13	1.14	+.44	Falls City	4.24	Lexington	T.
Nevada	27.9	-4.6	Logandale	66	5	Millett	-28	[1] 14	1.85	+.92	Marlette Lake	10.57	Mina	.35
New England	30.0	+3.4	Hartford, Conn	64	12	Enosburg Falls, Vt	-28	27	3.35		Mays Mill, Vt	5.39	Bar Harbor, Me	.90
New Jersey	39.6	+6.8	Runyon	72	12	Runyon	7	28	2.27	-1.74	Chatham	3.24	Pemberton	1.57
New Mexico	31.6	-1.5	Hope	74	26	Dulce	-38	2	.90	+.16	Dulce	4.50	Colmor	
New York	31.1	+4.5	Flushing	69	12	2 stations	-17	8	3.06	+.08	Gabriels	5.63	Chazy	.56
North Carolina	50.4	+7.9	Fayetteville	86	20	Altapass	14	16	6.91	+3.06	Rock House	17.88	Wilmington	2.64
North Dakota	21.0	+8.4	Cando	58	18	Park River	-21	4	.23	-.29	Ellendale	1.20	4 stations	
Ohio	39.8	+8.6	3 stations	71	11	2 stations	11	8	3.52	+.67	Middleport	5.18	Montpelier	1.84
Oklahoma	44.7	+5.3	Poteau	77	12	Kenton	6	14	1.23	-.42	Idabel	6.04	Blackwell	.09
Oregon	30.7	-1.6	2 stations	67	[1] 16	Senaca	-38	15	4.61	+.94	Gold Beach	23.66	Frenchglen	.26
Pennsylvania	38.1	+7.0	Hanover	70	12	Coudersport	-1	8	2.85	-.31	Elk Lick	5.49	Reading	1.27
South Carolina	53.5	+6.9	3 stations	85	[1] 12	Santuck	20	27	7.14	+3.52	Caesars Head	16.41	Myrtle Beach	1.65
South Dakota	25.0	+5.2	Spearfish	68	[1] 18	Pukwana	-17	13	1.06	+.48	Onaka	4.23	Britton	.13
Tennessee	49.7	+9.2	Newport	81	12	Rugby	19	16	8.78	+4.28	Covington	11.41	Bristol	4.99
Texas	50.5	+1.0	Riogrande	91	29	Romero	5	14	3.96	+1.77	Bronson	16.44	Follett	.20
Utah	21.2	-5.2	St. Georges	60	25	Woodruff	-29	15	1.59	+.32	Silver Lake	6.81	Antimony	.16
Virginia	46.1	+8.0	Diamond Springs	82	14	Dale Enterprise	14	16	2.95	-.36	Speers Ferry	6.93	Orange	.93
Washington	30.6	-1.7	Walla Walla (a)	62	19	Wilbur	-15	12	7.29	+1.95	Wynoochee Oxbow	36.00	Alpowa Ranch	1.29
West Virginia	42.0	+8.2	2 stations	75	11	2 stations	8	7	3.94	+.48	Morgantown	7.05	Brandywine	1.35
Wisconsin	30.4	+10.2	Racine	58	22	Rhinelander	-11	7	1.17	-.09	Beloit	2.80	Mellen	.15
Wyoming	20.9	+.3	Chugwater	71	18	2 stations	-36	15	.53	-.25	Bechler River	5.94	2 stations	
Alaska (November)	20.4	+3.9	Bell Island	56	3	Fort Yukon	-41	17	2.75	+.31	Mile Seven (Cordova).	15.90	Akiak	.10
Hawaii	66.5	-1.4	Waipahu	89	15	Kanalohuluhulu	40	7	7.21	-2.42	Kawainui (upper)	30.40	Ka Lae	
Porto Rico	74.6	+.2	San German	94	3	Guineo Reservoir	46	11	3.93	-.57	Rio Grande	11.92	Santa Rita	

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1931*

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with 0.01 or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							33.1	+3.7										70	3.19	−0.2										6.6		
Eastport	76	67	85	29.86	29.95	−0.03	27.5	+1.2	49	4	35	5	21	20	31	26	22	77	2.37	−1.4	18	8,864	nw.	31	nw.	5	2	4	25	8.5	2.9	0.0
Greenville, Me.	1,070	6		28.79	29.98		21.6		41	4	29	−7	21	14	30				3.40		15	6,685	nw.	27		26	6	5	20		24.5	0.0
Portland, Me.	103	82	117	29.88	30.01	−.02	31.8	+4.2	51	24	39	13	8	25	23	27	20	65	3.53	−.4	13	5,896	nw.	30	nw.	7	11	6	14	5.8	2.9	0.0
Concord	289	70	79	29.70	30.03	−.02	29.0	+2.2	56	12	38	5	9	20	32				4.70	+1.6	10	4,349	nw.	25	w.	7	12	3	16	5.8	2.2	0.0
Burlington	403	11	48	29.60	30.07	+.02	26.4	+2.0	52	12	34	1	28	18	37				2.17	+.3	13	7,855	s.	39	s.	21	5	4	22	7.6	4.1	T.
Northfield	876	12	60	29.08	30.07	+.02	24.0	+3.6	52	12	34	−5	6	14	30	21	18	82	2.01	−.5	16	5,095	n.	26	n.	5	5	9	17	7.2	7.0	0.2
Boston	125	106	165	29.89	30.03	−.02	36.6	+4.1	61	12	44	14	8	29	26	32	24	63	2.90	−.6	10	6,114	nw.	28	nw.	5	10	5	16	6.1	1.4	0.0
Nantucket	12	14	90	30.02	30.03	−.02	39.4	+3.6	55	22	46	19	8	33	24	36	31	73	4.05	+.3	12	11,148	nw.	40	sw.	7	6	4	21	7.4	T.	0.0
Block Island	26	11	46	30.01	30.04	−.02	39.6	+3.6	54	22	46	18	8	33	28	36	30	69	3.56	−.2	10	14,337	w.	55	w.	7	9	9	13	6.3	T.	0.0
Providence	160	215	251	29.87	30.05	−.01	37.0	+5.4	57	12	45	14	8	29	31	32	25	61	3.20	−.2	11	8,792	nw.	46	nw.	14	11	7	13	5.4	.3	0.0
Hartford	159	122		29.88	30.06	−.01	35.7	+5.9	64	12	43	14	8	28	25				3.00	−1.0	9		nw.				11	4	16	6.2	1.6	0.0
New Haven	106	74	153	29.96	30.08	+.01	37.6	+5.1	58	23	46	17	8	30	29	33	27	66	3.54	−.5	10	5,973	nw.	30	nw.	14	10	9	12	6.0	T.	0.0
Middle Atlantic States							42.9	+7.2										72	2.20	−1.1										6.4		
Albany	97	107	115	29.98	30.10	+.02	33.1	+4.6	55	12	40	10	8	26	26	29	24	71	2.62	.0	9	5,135	s.	23	sw.	25	10	8	13	5.6	.5	0.0
Binghamton	871	10	84	29.14	30.10	+.01	34.6	+6.4	56	24	42	12	8	27	27				2.25	−.1	15	4,255	nw.	25	nw.	7	5	3	23	7.7	3.2	T.
New York	314	414	454	29.74	30.10	+.01	40.6	+5.6	66	12	48	19	8	33	23	36	29	66	2.22	−1.4	9	11,908	nw.	58	nw.	14	7	9	15	6.5	T.	0.0
Bellefonte	1,050	5	36	28.98	30.12		35.6		59	12	44	11	8	27	33	31	28	78	1.81		11		w.	48	se.	11	3	10	18	7.6	.2	T.
Harrisburg	374	94	104	29.72	30.13	+.01	40.2	+7.5	62	12	47	22	8	33	23	35	28	66	1.70	−1.3	9	4,695	w.	38	w.	14	8	8	15	6.3	.8	0.0
Philadelphia	114	123	367	30.01	30.14	+.03	44.2	+7.9	65	12	51	23	8	37	24	38	31	62	1.78	−1.6	7	8,939	nw.	44	w.	14	7	9	15	6.3	T.	0.0
Reading	325	81	103	29.78	30.14		40.1	+7.9	64	12	46	21	8	34	21	36	32	75	1.27	−2.3	7	4,052	w.	25	w.	14	8	8	15	6.5	.5	0.0
Scranton	805	72	103	29.26	30.14	+.04	36.0	+5.3	59	12	44	15	8	28	28	33	29	76	1.35	−1.7	12	4,650	sw.	38	nw.	14	6	12	13	6.6	.9	0.0
Atlantic City	52	37	172	30.06	30.12	+.02	43.8	+7.4	67	12	52	21	8	36	26	39	34	70	2.57	−1.4	7	11,447	w.	49	w.	14	8	10	13	5.8	0.0	0.0
Cape May	17	13	49				44.4	+6.4	62	12	52	24	8	37	26	41	36	76	2.34	−1.4	6		nw.				7	11	13		~~T.~~	~~0.0~~
Sandy Hook	22	10	55	30.07	30.09		41.0		59	12	47	22	8	35	20	37	33	75	1.62	−2.4	7	10,935	w.	49	nw.	14	7	8	16	6.3	T.	0.0
Trenton	190	159	183	29.91	30.12		40.5	+6.1	67	12	48	20	8	32	23	36	30	68	2.36	−1.0	7	6,976	nw.	41	nw.	14	8	7	16	6.5	T.	0.0
Baltimore	123	100	215	30.00	30.14	+.01	45.7	+8.5	70	12	53	26	8	38	25	39	33	64	2.20	−1.2	7	6,674	sw.	43	sw.	14	7	11	13	6.5	.7	0.0
Washington	112	62	85	30.02	30.15	+.02	44.2	+7.6	70	14	52	24	8	36	31	39	33	68	2.03	−1.3	9	4,220	nw.	34	nw.	14	6	9	16	6.6	1.0	0.0
Cape Henry	18	8	54	30.13	30.15		51.8	+8.1	77	13	59	33	16	44	25	46	42	73	2.05	−1.4	9	9,307	sw.	48	n.	7	5	8	18	6.2	.0	0.0
Lynchburg	681	153	188	29.42	30.18	+.04	47.3	+7.8	73	19	56	21	27	38	26	42	38	76	2.74	−.5	10	4,766	w.	42	nw.	25	9	8	14	6.0	.0	0.0
Norfolk	91	170	205	30.07	30.17	+.04	51.9	+8.8	76	13	60	30	8	44	27	46	41	72	1.71	−1.6	9	8,583	w.	36	nw.	25	7	12	12	6.0	0.0	0.0
Richmond	144	11	52	30.01	30.17	+.03	47.8	+8.0	73	19	58	25	8	38	32	42	38	76	2.52	−.8	9	4,841	sw.	27	nw.	25	7	12	12	6.0	1.0	0.0
Wytheville	2,304	49	55	27.75	30.18	+.03	43.2	+7.9	69	13	51	18	27	35	27	39	36	81	4.18	+1.3	12	5,216	w.	27	e.	31	7	4	20	7.0	0.0	0.0
South Atlantic States							55.8	+8.5										82	5.70	+2.3										6.4		
Asheville	2,253	89	104	27.80	30.20	+.04	47.4	+9.6	73	12	57	23	16	38	31	42	39	82	6.49	+3.3	14	5,806	nw.	33	e.	31	10	10	11	5.8	T.	0.0
Charlotte	779	55	62	29.33	30.18	+.02	50.6	+7.6	79	20	59	28	8	42	27	46	43	84	11.24	+7.4	12	3,343	sw.	20	sw.	24	4	13	14	6.7	0.0	0.0
Greensboro	886	6	56	29.21	30.19		46.7		77	20	57	21	3	37	30	41	39	85	5.35		13	4,994	sw.	30	nw.	14	7	8	16	6.2	0.0	0.0
Hatteras	11	5	50		30.16	+.03	56.2	+6.1	73	22	62	36	27	50	19			84	5.52	+1.3	8	9,113	ne.	35	nw.	26	12	6	13		0.0	0.0
Raleigh	376	103	146	29.77	30.18	+.03	51.2	+8.2	79	12	60	29	8	42	26	45	40	73	6.12	+2.5	12	5,464	sw.	28	nw.	14	8	9	14	6.1	0.0	0.0
Wilmington	72	73	106	30.10	30.18	+.03	56.4	+7.3	80	20	66	31	27	47	31	51	48	79	2.64	−.1	13	5,676	sw.	28	nw.	28	12	6	13	5.5	0.0	0.0
Charleston	48	11	92	30.16	30.16	+.03	61.3	+9.6	81	20	68	40	27	54	21	56	54	84	2.25	−.5	8	7,206	ne.	30	ne.	2	7	11	13	6.2	0.0	0.0
Columbia, S. C.	351	41	57	29.79	30.18	+.02	53.6	+6.4	81	20	62	32	8	45	35	48	44	78	6.46	+3.4	10	4,107	ne.	21	sw.	14	6	13	12	6.3	0.0	0.0
Due West	711	10	55	29.41	30.20		51.5		79	20	60	30	8	43	27				11.68		16	5,635	ne.	27	e.	31	4	9	18	7.0	~~0.0~~	~~0.0~~
Greenville, S. C.	1,039	139	146	29.06	30.17		51.2	+9.0	78	20	59	28	8	43	25	46	44	84	12.56	+7.7	15	5,517	ne.	30	ne.	3	5	10	16	6.3	0.0	0.0
Augusta	182	62	77	29.96	30.16	.00	56.0	+7.9	80	13	65	31	27	47	35	50	47	82	5.35	+2.1	11	3,196	nw.	20	nw.	24	4	13	14	6.8	0.0	0.0
Savannah	65	150	194	30.08	30.15	.00	62.8	+10.4	82	4	71	40	27	55	25	56	54	82	1.50	−1.4	11	7,263	ne.	26	ne.	2	7	8	16	6.7	0.0	0.0
Jacksonville	43	209	245	30.09	30.14	.00	67.6	+11.3	81	14	74	46	27	61	23	62	59	83	2.57	−.4	9	7,097	s.	28	sw.	4	5	11	15	6.8	0.0	0.0
Florida Peninsula							74.8	+8.3										82	2.24	+0.4										5.4		
Key West	22	10	64	30.05	30.07	−.01	76.6	+6.3	83	9	81	65	28	73	12	71	69	81	4.04	+2.4	10	6,985	e.	20	s.	31	12	14	5	4.5	0.0	0.0
Miami	25	124	168	30.08	30.11	.00	75.4	+7.4	82	5	79	60	29	72	18	69	67	78	1.49	−.2	9	6,803	e.	41	sw.	31	7	18	6	5.6	0.0	0.0
Tampa	35	86	197	30.07	30.11	−.01	72.4	+11.3	86	1	80	53	27	64	24	66	65	87	1.20	−.9	4	6,511	s.	42	nw.	31	5	11	15	6.5	0.0	0.0
Titusville	44	5		30.08	30.14		72.6		86	1	80	54	29	65	27				3.88		9		se.				10	17	4	5.1	0.0	0.0
East Gulf States							57.7	+8.2										83	8.75	+3.9										7.1		
Atlanta	1,173	190	198	28.91	30.17	+.01	51.4	+6.7	74	12	59	31	8	44	29	48	45	83	12.07	+7.4	19	6,672	e.	31	e.	8	7	5	19	6.9	0.0	0.0
Macon	370	78	87	29.76	30.17	+.01	55.3	+7.8	79	12	64	32	27	46	32	50	46	79	6.09	+2.1	15	3,793	n.	18	nw.	14	6	2	23	7.5	0.0	0.0
Thomasville	273	49	103	29.83	30.13	−.02	63.6	+11.1	81	11	72	42	26	55	27	58	55	82	7.81	+3.5	10	5,168	s.	27	nw.	31	3	11	17	7.2	0.0	0.0
Apalachicola	36	11	51	30.07	30.11		66.0		82	14	72	46	26	60	21	62	61	89	7.81	+2.7	7	6,326	se.	28	se.	8	4	8	19	7.0	0.0	0.0
Pensacola	56	149	185	30.04	30.10	−.05	63.0	+9.0	76	23	69	44	26	57	23	60	58	84	8.98	+4.3	14	9,306	e.	46	w.	31	6	10	15	6.5	0.0	0.0
Anniston	741	9	57				53.0	+8.8	76	11	61	32	5	45	31				10.96	+5.9	19	3,718	s.	24	sw.	8	4	10	17		0.0	0.0
Birmingham	700	11	48	29.37	30.14	−.02	54.4	+8.0	79	13	62	33	15	47	33	50	47	82	8.33	+3.2	14	5,136	s.	28	se.	8	4	8	19	7.2	0.0	0.0
Mobile	57	125	161	30.03	30.09	−.06	61.3	+9.1	78	24	69	43	26	54	23	58	55	86	9.18	+4.2	15	6,588	s.	30	w.	31	4	8	19	7.4	0.0	0.0
Montgomery	223	100	112	29.89	30.14	−.02	57.5	+8.1	81	11	65	39	15	50	28	52	49	80	7.24	+2.4	17	4,475	e.	27	sw.	31	5	7	19	7.2	0.0	0.0
Corinth	469	6					52.8		73	23	61	29	15	44	31				10.40		17		se.				2	17	12		0.0	0.0
Meridian	375	87	95	29.71	30.11	−.05	55.9	+8.2	81	11	64	35	5	48	29	51	48	82	9.16	+3.9	17	3,852	ne.	22	e.	8	7	5	19	7.0	0.0	0.0
Vicksburg	247	65	73	29.83	30.12	−.03	56.2	+6.2	79	12	64	36	15	49	26	51	47	78	8.70	+3.4	13	4,802	ne.	32	e.	8	5	10	16	7.2	0.0	0.0
New Orleans	53	76	84	30.02	30.07	−.06	63.0	+7.4	84	11	70	46	26	56	23	58	50	84	8.63	+3.8	16	4,547	ne.	22	e.	8	6	8	17	6.9	0.0	0.0
West Gulf States							53.4	+3.0										80	5.14	+2.2										6.6		
Shreveport	249	204	220	29.81	30.09	−.04	53.0	+3.9	77	23	60	36	15	46	31	49	45	80	10.43	+6.1	16	6,564	s.	33	w.	31	7	10	14	6.8	0.0	0.0
Bentonville	1,303	11	44	28.66	30.05	−.08	45.5	+8.0	67	23	54	22	15	37	31				.59		11	3,303	s.	17	sw.	11	14	4	13		0.0	0.0
Fort Smith	457	79	94	29.58	30.07	−.06	48.3	+6.2	70	12	57	28	15	40	31	43	39	76	1.46	−1.3	13	4,511	e.	24	sw.	11	9	6	16	6.2	0.0	0.0
Little Rock	357	136	153	29.72	30.10	−.04	49.8	+5.6	72	11	56	32	2	43	25	46	43	80	9.14	+5.0	18	5,203	sw.	24	s.	11	7	4	20	7.4	0.0	0.0
Austin	605	136	148	29.43	30.06		53.2	+2.2	76	23	62	30	18	44	34	48	45	78	4.24	+1.6	14	5,348	n.	28	nw.	31	8	8	15	6.4	0.9	0.0
Brownsville	57	83	100	29.98	30.04		61.8	+1.6	82	11	69	40	20	55	27	57	54	83	1.85	+.3	9	7,747	nw.	33	se.	29	5	9	17	6.9	0.0	0 0
Corpus Christi	20	11	78	30.04	30.06	−.06	59.0	+1.0	79	30	65	40	20	52	29	55	52	83	1.77	+.3	9	7,426	nw.	32	s.	10	4	9	18	7.1	0.0	0.0
Dallas	512	220	227	29.50	30.06		50.8		73	23	58	32	14	44	31				2.81	+.4	14	8,027	se.	44	w.	31	10	5	16	6.2	0.0	0.0
Fort Worth	670	106	114	29.34	30.06	−.06	51.0	+3.5	72	28	59	32	15	43	28	45	41	73	2.73	+.9	8	5,127	sw.	26	nw.	31	7	8	16	6.5	0.0	0.0
Galveston	54	106	114	30.02	30.06	−.04	57.4	+1.0	75	13	62	41	20	52	26	54	52	87	7.81	+4.1	14	7,745	se.	26	nw.	14	7	7	17	6.7	0.0	0.0
Houston	138	292	314	29.92	30.07		56.0	+1.6	80	22	63	39	20	49	32				6.01	+1.8	16	8,756	s.	30	s.	10	5	11	15	6.9	0.0	0.0
Palestine	510	64	72	29.55	30.09	−.03	52.0	+2.1	79	23	60	32	18	44	32	48	45	81	7.54	+3.9	17	4,993	ne.	22	ne.	1	8	7	16	6.7	0.0	0.0
Port Arthur	34	58	66	30.01	30.05		56.4		77	13	63	38	4	50	28				9.02	+3.8	14	5,988	s.	26	ne.	7	5	9	17	7.1	0.0	0.0
San Antonio	693	242	301	29.32	30.05	−.06	55.2	+1.5	79	27	63	34	17	47	27	50	45	75	2.79	+1.2	13	7,464	n.	31	nw.	30	7	11	13	6.2	0.0	0.0
Taylor	571	38	51	29.49	30.10	−.01	52.2	+1.6	78	23	61	31	18	43	33				4.30	+2.0	11	5,107	n.	25	s.	29	7	15	9	5.8	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
Ohio Valley and Tennessee							**44.9**	**+8.4**										**80**	**5.15**	**+1.7**										**7.5**		
Chattanooga	762	190	215	29.33	30.16	0.00	50.7	+7.4	72	12	57	35	16	44	30	47	43	77	11.36	+6.2	16	4,882	ne.	28	nw.	14	6	9	16	6.9	0.0	0.0
Knoxville	995	102	111	29.10	30.17	+.01	49.2	+8.9	74	12	56	30	27	42	25	46	43	83	7.92	+3.4	17	3,994	ne.	21	sw.	24	4	9	18	7.5	T.	0.0
Memphis	399	78	86	29.68	30.11	-.04	51.6	+8.0	74	20	58	31	2	45	26	48	46	83	10.19	+5.7	17	4,616	e.	26	sw.	29	9	6	16	6.4	0.0	0.0
Nashville	546	168	191	29.57	30.16	+.01	50.2	+9.2	69	12	57	30	2	44	24	47	44	82	6.33	+2.1	14	5,946	s.	36	w.	13	5	5	21	7.6	0.0	0.0
Lexington	989	193	230	29.09	30.18	+.04	44.4	+8.6	66	11	51	25	2	38	25				5.84	+2.1	19	8,718	sw.	35	sw.	11	4	4	23	8.0	0.0	0.0
Louisville	525	188	234	29.57	30.17	+.03	45.1	+7.5	69	11	52	28	2	39	23	42	39	81	3.99	+.2	13	6,070	s.	32	w.	24	5	4	22	7.9	0.0	0.0
Evansville	431	76	116	29.66	30.14	+.01	45.8	+8.7	73	11	52	28	2	40	23	43	40	81	4.87	+1.3	16	5,363	e.	29	sw.	11	4	9	18	7.2	0.0	0.0
Indianapolis	822	194	230	29.22	30.13	+.01	41.2	+9.0	66	11	47	23	8	35	21	38	34	79	4.41	+1.4	12	7,277	sw.	30	w.	24	6	8	17	6.8	T.	0.0
Royal Center	736	11	55	29.30	30.12		37.8		62	11	44	18	8	32	24				2.16	-.5	11	7,141	sw.	35	e.	31	7	6	18	7.1	0.2	0.0
Terre Haute	575	96	129	29.50	30.13		41.9		67	11	48	26	2	36	22	39	36	83	4.28	+1.4	11	5,638	s.	26	sw.	11	8	6	17	6.6	T.	0.0
Cincinnati	627	11	51	29.46	30.16	+.03	42.5	+9.1	70	11	50	22	2	35	24	39	36	82	3.35	+.4	14	4,803	sw.	24	w.	14	4	4	23	7.8	0.0	0.0
Columbus	822	216	230	29.25	30.14	+.02	41.1	+8.7	66	11	48	21	8	34	23	38	34	80	3.29	+.6	10	7,209	sw.	37	w.	14	4	7	20	7.7	T.	0.0
Dayton	899	137	173	29.17	30.15		41.4	+8.8	67	11	48	22	8	35	21	38	35	82	4.29	+1.5	11	5,518	sw.	26	w.	24	4	9	18	7.6	T.	0.0
Elkins	1,947	59	67	28.09	30.20	+.08	40.6	+7.9	67	11	50	13	8	31	34	37	34	82	3.81	+.4	16	4,070	w.	27	w.	14	3	4	24	8.5	.3	0.0
Parkersburg	637	77	82	29.51	30.18	+.04	43.1	+7.9	66	11	51	21	8	36	28	39	34	75	3.54	+.5	15	3,767	se.	27	nw.	14	4	4	23	8.1	0.0	0.0
Pittsburgh	842	353	410	29.22	30.15	+.04	41.5	+7.3	62	13	48	21	8	35	24	38	33	75	2.94	+.1	13	7,386	w.	36	w.	14	3	6	22	8.0	T.	0.0
Lower Lake Region							**35.8**	**+6.7**										**78**	**2.71**	**0.0**										**7.7**		
Buffalo	767	247	280	29.23	30.08	+.02	35.6	+5.8	56	24	42	15	8	29	24	32	29	80	2.08	-1.3	15	12,946	w.	62	w.	7	3	6	22	7.7	2.9	0.0
Canton	448	10	61	29.56	30.06		24.8	+2.1	50	12	34	-5	8	16	33				2.85	+.2	15	6,025	sw.	35	sw.	17	5	6	20	7.3	9.9	.9
Ithaca	836	74	100	29.16	30.09		35.2	+6.2	55	12	43	14	27	28	26	31	27	75	3.06	+.7	17	7,293	nw.	33	nw.	7	3	4	24	8.3	2.1	0.0
Oswego	335	71	85	29.71	30.09	+.03	33.2	+4.2	55	24	40	11	8	26	28	30	26	76	2.65	-.8	15	8,014	s.	33	w.	7	2	3	26	8.7	3.0	T.
Rochester	523	86	102	29.52	30.10	+.04	35.2	+5.9	56	12	42	12	8	29	27	31	27	75	2.74		15	6,435	w.	36	w.	17	4	6	21	8.0	5.0	T.
Syracuse	596	65	79	29.44	30.10	+.03	34.2	+5.9	56	24	41	14	8	27	30				2.60	-.5	14	4,948	w.	26	nw.	7	2	14	15	7.2	5.2	0.0
Erie	714	130	166	29.32	30.11	+.04	38.4	+6.5	60	24	44	23	27	33	22	35	31	77	2.80		11	10,592	sw.	37	w.	7	6	6	19	7.2	.2	0.0
Cleveland	762	267	337	29.27	30.11	+.02	40.2	+9.0	64	11	46	24	8	34	24	36	31	73	2.65	+.2	9	10,212	sw.	48	w.	7	2	5	24	8.5	T.	0.0
Sandusky	629	65	67	29.41	30.11	+.02	38.9	+7.7	64	11	45	19	8	33	22				2.37	+.1	9	6,316	sw.	27	nw.	7	4	5	22	7.9	.2	0.0
Toledo	628	208	243	29.43	30.13	+.05	38.2	+7.8	64	11	44	18	8	32	23	35	31	78	3.22	+.9	8	9,134	sw.	38	sw.	24	7	6	18	6.9	T.	0.0
Fort Wayne	856	100	119	29.18	30.12		38.2	+10.9	63	11	44	19	8	33	20	36	33	85	2.88	+.3	14	6,585	sw.	30	sw.	24	7	3	21	7.5	T.	0.0
Detroit	730	218	258	29.31	30.12	+.05	37.2	+7.9	62	11	43	19	8	32	20	34	31	81	2.66	+.3	10	7,543	sw.	32	sw.	11	4	6	21	7.7	1.3	0.0
Upper Lake Region							**32.8**	**+8.1**										**81**	**1.86**	**-.3**										**7.5**		
Alpena	609	13	89	29.40	30.09	+.07	31.2	+6.4	52	18	37	6	8	25	22	29	25	78	2.23	+.2	10	7,279	nw.	32	e.	31	4	8	19	7.7	11.6	2.8
Escanaba	612	54	60	29.40	30.09	+.06	30.8	+8.4	50	18	36	9	8	26	27	29	25	70	1.16	-.6	7	6,646	sw.	33	n.	4	5	5	21	7.5	5.1	0.0
Grand Haven	632	54	89	29.40	30.10	+.05	35.3	+6.0	51	11	41	12	8	30	22	33	31	85	2.89	+.4	9	8,065	sw.	40	w.	7	3	4	24	8.4	6.3	.1
Grand Rapids	707	70	244	29.32	30.11	+.03	35.8	+7.2	55	11	41	17	5	30	23	33	30	81	2.64	+.1	9	8,043	sw.	47	sw.	11	4	4	23	8.2	7.0	0.0
Houghton	668	64	99	29.31	30.06	+.04	29.8	+8.0	45	22	34	9	8	25	25				.77	-2.3	7	6,264	w.	36	w.	6	1	7	23	8.0	4.8	0.0
Lansing	878	6	88	29.13	30.10		33.6	+6.4	57	11	40	12	8	28	22	32	31	92	3.79	+1.7	11	6,231	sw.	31	sw.	11	5	6	20	7.5	5.5	0.0
Ludington	637	60	66	29.38	30.39		34.8	+6.4	48	11	40	14	8	30	16	32	29	81	2.22	-.3	13	7,749	e.	37	sw.	2	4	12	15	6.8	5.0	T.
Marquette	734	77	111	29.24	30.06	+.04	31.7	+9.1	53	18	36	10	7	27	24	29	25	78	1.09	-1.6	10	6,742	w.	35	sw.	8	1	6	24	8.5	3.3	0.0
Port Huron	638	70	120	29.38	30.09	+.03	35.2	+7.6	59	11	41	14	8	30	21	32	30	82	1.82	-.2	13	7,569	w.	36	nw.	7	4	9	18	7.3	3.0	0.0
Sault Sainte Marie	614	11	52	29.37	30.09	+.00	28.1	+7.6	44	18	34	2	5	22	30	27	23	80	1.86	-.5	14	5,562	se.	32	nw.	7	5	7	19	7.6	8.5	0.0
Chicago	673	7	131	29.37	30.12	+.04	38.4	+9.6	58	11	43	20	7	34	20	35	32	80	2.28	+.2	12	7,307	sw.	30	sw.	11	8	7	16	6.5	5.6	0.0
Green Bay	617	109	141	29.40	30.08	+.04	32.0	+9.7	50	18	37	6	7	27	21	29	26	79	1.10	-.6	8	7,191	sw.	34	ne.	24	6	4	21	7.7	2.8	0.0
Milwaukee	681	125	221	29.34	30.10	+.04	36.2	+10.1	53	22	42	11	7	31	23	33	29	79	1.85	+.1	8	9,540	w.	33	e.	31	6	6	19	7.1	5.3	.3
Duluth	1,133	5	47	28.79	30.05	.00	26.6	+10.7	48	18	33	-6	7	21	30	25	22	83	.32	-.8	5	8,482	w.	38	ne.	30	9	3	19	6.8	3.0	0.0
North Dakota							**21.5**	**+9.1**										**87**	**.49**	**-.1**										**5.9**		
Moorhead	940	50	58	29.00	30.06	-.02	21.2	+9.7	40	18	28	-12	7	14	33	20	19	91	.21	-.5	4	5,201	s.	20	s.	20	5	8	18	7.3	3.0	2.6
Bismarck	1,674	8	57	28.18	30.03	-.05	21.4	+6.7	44	22	30	-9	13	13	32	19	17	85	.53		5	4,104	e.	21	se.	7	13	8	10	4.9	7.4	4.2
Devils Lake	1,478	11	44	28.39	30.03	-.03	20.0	+10.5	38	2	28	-10	7	13	33	19	18	92	.09	-.4	4	5,878	s.	21	nw.	6	4	12	15	6.8	1.2	1.1
Ellendale	1,457	10	56	28.43	30.05		20.6		45	18	29	-8	14	12	32				1.20	+.7	9	7,584	nw.	25	e.	29	8	10	13	5.9	11.4	10.2
Grand Forks	833	12	67				19.6		38	18	27	-15	7	13	32	18			.14		3		se.	28	nw.	6	5	10	16		2.3	10.8
Williston	1,878	41	48	27.95	30.00	-.06	23.4	+9.6	47	25	32	-8	12	14	29	20	17	79	.40	-.2	2	3,994	sw.	25	se.	21	13	8	10	4.6	4.3	1.7
Upper Mississippi Valley							**37.1**	**+10.3**										**82**	**2.25**	**+0.6**										**6.8**		
Minneapolis	918	102	208	29.03	30.04		30.0	+10.4	48	22	36	-1	7	24	24				.71	-.3	8	7,157	se.	31	e.	29	7	6	18	6.7	3.5	T.
St. Paul	837	114	149	29.13	30.06	-.02	29.8	+10.8	47	19	36	0	7	24	26				.77	-.3	8	5,579	s.	26	nw.	6	9	5	17	6.6	4.8	.2
La Crosse	714	11	48	29.29	30.08	.00	32.6	+10.3	53	18	38	6	7	27	25	30	27	83	2.20	+.9	12	3,355	s.	19	sw.	2	6	4	21	7.3	6.4	2.0
Madison	974	70	78	29.01	30.10	+.02	33.0	+10.2	51	18	38	9	7	28	22	31	28	83	1.64		9	6,167	sw.	31	ne.	31	6	5	20	7.1	4.8	1.1
Wausau	1,247	4	62	28.71	30.08		28.0		45	18	34	-1	7	22	25				1.28	-.2	8	4,354	w.	24	w.	6	7	3	21	7.4	3.7	0.0
Charles City	1,015	10	51	28.98	30.09	-.01	32.0	+11.6	48	18	38	9	7	26	22	29	27	85	2.22	+.9	12	4,762	se.	24	ne.	30	10	3	18	6.5	4.4	2.0
Davenport	606	118	143	29.42	30.10	.00	37.1	+10.0	57	18	43	19	14	32	25	34	31	80	2.68	+1.2	12	7,005	sw.	38	ne.	31	6	7	18	6.9	6.7	.1
Des Moines	861	5	99	29.15	30.08	-.03	35.8	+9.8	55	18	42	14	14	30	20	33	31	85	3.72	+2.5	14	6,523	se.	28	n.	31	8	2	21	7.0	5.7	.8
Dubuque	700	81	96	29.32	30.10	.00	35.2	+10.5	54	18	40	15	7	30	25	32	29	80	1.51	+.1	11	3,886	se.	19	ne.	31	7	4	20	7.1	5.7	2.8
Keokuk	614	64	78	29.42	30.11	-.01	39.6	+10.0	60	18	46	20	14	33	24	36	33	81	2.01	+.6	12	4,737	sw.	21	e.	31	9	3	19	6.6	3.5	0.0
Cairo	358	87	93	29.73	30.12	-.03	47.8	+10.0	73	11	54	27	15	42	23	45	41	80	4.15	+.8	11	5,259	ne.	25	s.	11	4	9	18	7.4	.0	0.0
Peoria	609	11	45	29.44	30.12	+.01	38.6	+10.5	57	11	45	21	2	32	25	36	33	85	2.26	+.5	12	4,457	sw.	21	ne.	31	10	4	17	6.4	4.9	0.0
Springfield, Ill.	636	5	191	29.41	30.10	-.02	41.0	+9.3	61	11	47	27	8	35	22	38	35	84	2.80	+.6	12	8,226	s.	33	s.	10	6	9	16	6.8	1.0	0.0
Hannibal	534	74	109	29.52	30.10	-.02	41.6	+10.1	62	18	48	23	14	35	29				2.49	+1.0	12	5,218	sw.	26	ne.	31	10	6	15	6.1	4.0	0.0
St. Louis	568	265	303	29.48	30.10	-.03	45.2	+10.5	66	23	52	30	14	39	23	40	36	75	3.28	+1.1	10	7,262	s.	28	sw	11	7	7	17	6.7	.0	0.0
Missouri Valley							**35.5**	**+7.8**										**82**	**1.92**	**+.9**										**5.6**		
Columbia, Mo.	784	6	84	29.24	30.09	-.03	43.4	+10.2	65	18	51	25	14	36	25				2.52	+.7	11	4,715	sw.	20	nw.	24	6	12	13	6.3	1.6	0.0
Kansas City	963	161	181	29.02	30.08	+.04	42.5	+10.0	66	30	50	24	14	36	21	39	35	79	2.54	+1.2	11	5,580	sw.	28	sw.	23	8	12	11	5.8	2.4	0.0
St. Joseph	967	11	49	29.00	30.06		40.0		61	19	48	19	14	32	20	36	34	83	3.38	+2.4	11	5,156	se.	23	nw.	11	13	5	13	5.	3.9	1.4
Springfield, Mo.	1,324	98	104	28.64	30.07	-.06	44.8	+8.6	69	23	52	26	14	37	25	40	35	75	1.65	-.7	8	6,293	se.	24	se.	26	13	6	12	5.1	0.0	0.0
Iola	984	11	50	29.00	30.07	-.05	42.4	+8.5	64	29	51	21	14	34	29				.68	-.7	5	3,310	s.	16	s.	29	12	6	13	5.4	T.	0.0
Topeka	987	92	107				41.0	+9.0	63	19	49	22	14	33	25				1.48	+.5	7	5,208	sw.	31	ne.	31	11	5	15	5.5	1.3	0.0
Lincoln	1,189	11	81	28.75	30.06	-.06	37.0	+9.4	57	25	44	18	1	30	24	34	31	84	2.26	+1.5	7	6,008	s.	24	n.	31	10	5	16	6.0	6.6	6.5
Omaha	1,105	115	122	28.85	30.07	-.04	37.0	+10.6	57	18	43	19	14	31	24	34	30	80	3.33	+2.4	9	4,510	sw.	21	ne.	31	12	3	16	5.7	3.8	3.0
Valentine	2,598	47	54	27.26	30.07	-.03	26.8	+2.2	59	28	38	-6	13	16	32	23	20	82	.61		4	4,537	w.	20	e.	29	11	8	12	5.5	5.9	4.2
Sioux City	1,135	94	164	28.80	30.05	-.07	32.3	+9.2	53	18	38	10	14	26	25	30	27	83	1.83	+.9	8	7,453	s.	30	s.	8	9	7	15	6.0	1.4	1.1
Huron	1,306	59	74	28.61	30.07	-.03	23.8	+5.1	45	26	32	-7	14	16	29	22	20	88	2.15	+1.6	8	5,225	se.	22	se.	7	15	4	12	4.9	11.4	10.0
Pierre	1,572	70	75	28.32	30.05	-.05	24.8	+3.0	50	28	33	-5	14	17	32	22	19	81	.88	+.4	4	3,804	e.	24	ne.	6	12	10	9	5.0	7.9	7.1
Yankton	1,233	49	57	28.71	30.08	-.03	30.0	+7.2	53	22	36	8	7	24	26				1.67	+.8	6	4,273	w.	19	e.	30	13	3	15	5.5	7.5	6.7

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with 0.01 or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							24.9	+1.1										76	0.51	-0.3										5.3		
Billings	3,140	5					28.6		58	18	41	-2	12	16	37				.06		2		nw.				19	7	5		1.0	0.0
Havre	2,505	11	67	27.25	29.97	-0.08	23.4	+3.0	52	24	33	-17	12	14	35	21	18	84	.34	-.3	5	6,320	sw.	28	sw.	24	9	11	11	5.4	7.1	.3
Helena	4,124	89	113	25.71	30.03	-.10	25.9	+1.7	54	18	33	1	1	18	29	22	16	68	.16	-.6	5	3,983	sw.	35	sw.	27	5	13	13	6.5	2.5	1.0
Kalispell	2,973	48	56	26.88	30.03	-.04	25.6	+.7	46	18	31	4	14	20	21	24	23	90	1.72	+.3	14	2,279	nw.	17	se.	28	1	5	25	8.8	16.4	10.8
Miles City	2,371	48	55	27.42	30.07	-.03	22.1	+1.1	45	29	33	-12	12	12	31	20	18	87	.55	-.1	4	2,493	s.	21	nw.	29	13	11	7	4.5	6.5	5.0
Rapid City	3,259	50	58	26.54	30.06	-.03	31.6	+4.7	59	21	42	7	13	21	30	26	20	70	.62	+.2	4	3,644	w.	23	w.	21	11	11	9	4.8	6.0	5.2
Cheyenne	6,088	84	101	23.92	30.04	-.05	32.6	+4.1	67	18	44	3	12	21	40	24	14	50	.17	-.4	2	7,899	w.	40	nw.	29	15	8	8	4.2	2.3	1.8
Lander	5,372	60	68	24.59	30.22	-.07	13.2	-7.2	50	21	24	-18	13	2	38	10	8	85	T.	-.7	0	1,768	sw.	31	sw.	21	22	8	1	2.4	.1	2.0
Sheridan	3,790	10	47	26.01	30.06		23.3		48	28	36	-3	31	11	39	18	14	77	.19	-.4	3	1,675	s.	22	nw.	29	13	13	5	4.1	3.5	2.8
Yellowstone Park	6,241	11	48	23.82	30.05	-.11	21.5	-.1	49	18	29	-6	14	14	26	18	14	72	1.14	-.4	16	5,347	s.	29	sw.	21	6	7	18	7.1	19.6	15.4
North Platte	2,821	11	51	27.04	30.07	-.03	28.6	+1.9	56	22	39	2	14	18	32	24	21	82	.15	-.4	2	3,760	w.	27	n.	30	12	7	12	5.1	.9	.8
Middle Slope							39.0	+5.6										69	.53	-.3										4.8		
Denver	5,292	106	113	24.66	30.03	-.05	35.8	+3.5	64	17	46	8	13	25	34	27	15	46	.03	-.7	2	4,140	s.	22	n.	30	17	12	2	3.4	.8	0.0
Pueblo	4,685	80	86	25.25	30.05	-.03	33.2	+1.7	60	28	48	3	14	18	44	26	17	57	.02	-.5	1	3,833	nw.	33	w.	29	16	13	2	3.5	.2	0.0
Concordia	1,392	50	58	28.56	30.08	-.03	38.9	+8.2	58	25	47	21	1	31	25	34	32	87	.91	+.3	7	4,422	sw.	27	s.	26	13	9	9	4.6	1.2	.4
Dodge City	2,500	88	100	27.41	30.07	-.03	38.8	+6.2	67	22	49	17	14	29	32	33	28	74	.47	-.1	6	7,857	nw.	44	n.	31	16	5	10	4.5	.6	.5
Wichita	1,358	139	158	28.59	30.05	-.06	42.1	+7.5	63	29	49	23	14	35	24	38	33	73	.69	-.3	7	6,733	s.	32	s.	26	10	6	15	6.2	T.	T.
Oklahoma City	1,214	10	47	28.76	30.06	-.05	45.6	+6.3	67	29	53	25	14	38	24	40	36	77	1.08	-.4	9	5,476	s.	22	nw.	13	7	9	15	6.5	T.	0.0
Southern Slope							44.0	-.1										73	1.64	+.7										5.6		
Abilene	1,738	10	52	28.24	30.08	-.03	46.6	+.6	71	12	55	26	15	38	29	41	37	76	1.96	+.6	7	5,435	s.	30	nw.	31	10	4	17	6.3	6.5	0.0
Amarillo	3,676	10	49	26.26	30.06	-.03	40.3	+3.3	68	28	49	20	14	31	29	33	27	69	1.24	+.4	6	5,971	sw.	35	w.	30	10	6	15	5.7	11.2	0.0
Del Rio	944	64	71	29.05	30.05	-.05	51.5	-.7	76	12	61	31	17	42	32	47	43	78	1.54	+.8	8	4,506	nw.	27	nw.	13	9	9	13	5.8	0.0	0.0
Roswell	3,566	75	85	26.40	30.10	+.03	37.5	-3.7	67	26	49	4	3	26	34	31	25	69	1.80	+1.1	6	3,845	n.	35	nw.	30	13	8	10	4.7	16.2	0.0
Southern Plateau							39.1	-2.6										62	.75	+.1										3.7		
El Paso	3,778	152	175	26.22	30.08	+.05	43.8	-1.1	65	26	54	23	31	33	33	36	27	58	.30	-.2	6	5,909	nw.	37	w.	10	16	9	6	3.8	3.8	0.0
Albuquerque	4,972	51	66	25.08	30.11		33.7		55	22	45	13	14	23	32	27	19	59	.07		1	3,213	ne.	29	w.	10	15	9	7	3.9	T.	0.0
Santa Fe	7,013	38	53	23.21	30.13	+.07	27.7	-3.0	54	19	38	0	13	17	30	22	16	64	.50	-.2	4	3,858	n.	25	n.	30	15	7	9	4.4	6.1	.6
Flagstaff	6,907	10	59	23.31	30.09	+.03	22.8	-5.6	52	19	37	-19	13	9	49	20		83	2.39		8		sw.	26	n.	16	11	12	8		26.0	5.5
Phoenix	1,108	10	107	28.87	30.04	.00	49.7	-2.3	70	24	62	28	16	38	36	42	33	58	.75	-.2	3	2,809	e.	18	w.	12	17	8	6	3.6	0.0	0.0
Yuma	141	9	54	29.91	30.06	+.01	53.2	-2.0	70	19	64	36	4	42	29	43	32	49	.59	+.1	2	3,577	n.	25	ne.	6	20	9	2	2.7	0.0	0.0
Independence	3,957	6	27	25.98	30.09	-.03	37.6	-1.7	68	21	50	14	13	26	38	29			1.63	+.8	5		nw.				13	8	10		0.0	0.0
Middle Plateau							25.1	-5.1										76	1.19	+0.2										5.6		
Reno	4,532	74	81	25.41	30.05	-0.10	31.0	-2.7	62	18	41	2	15	21	34	27	22	71	2.19	+1.2	12	3,241	se.	32	se.	26	8	7	16	6.0	7.2	T.
Tonopah	6,090	12	20				26.8		49	19	32	7	14	21	24	23	18	69	.50		5		se.								0.0	0.0
Winnemucca	4,844	18	56	25.60	30.10	-.08	26.9	-3.1	52	7	37	-7	15	16	31	23	20	79	1.17	+.1	12	5,061	ne.	27	s.	28	10	6	15	5.8	5.9	0.8
Modena	5,473	10	43	24.62	30.17	+.05	19.0	-9.1	44	20	32	-17	13	6	39	17	14	86	.77	-.1	12	5,698	w.	32	nw.	28	10	7	14	5.6	11.9	4.6
Salt Lake City	4,360	163	203	25.66	30.14	-.01	27.9	-4.0	53	25	35	5	16	21	28	25	20	71	1.42	0.0	12	3,914	s.	28	se.	25	11	6	14	5.7	19.5	3.5
Grand Junction	4,602	60	68	25.46	30.18	+.08	20.8	-6.7	42	28	31	-9	16	10	36	18	16	83	.42	-.2	6	2,696	nw.	22	s.	29	12	10	9	4.7	3.8	0.0
Northern Plateau							28.1	-3.3										83	2.48	+.8										7.7		
Baker	3,471	48	53	26.42	30.11	-.05	23.4	-3.9	41	24	31	-3	15	16	23	21	18	76	2.03	+.3	20	4,040	se.	27	sw.	27	7	2	22	7.4	19.4	8.1
Boise	2,739	79	87	27.21	30.16	-.04	28.6	-3.5	51	24	35	2	16	22	20	26	22	79	1.83	+.3	17	3,413	se.	25	se.	28	5	3	23	8.0	11.4	4.9
Lewiston	757	40	48	29.22	30.05	-.08	33.8	-1.9	56	24	39	13	1	28	25				1.92	+.4	13	2,386	e.	17	ne.	6	5	5	21	7.4	5.0	.1
Pocatello	4,477	60	68	25.48	30.17	-.02	23.7	-4.0	48	21	32	-13	15	16	31	22	18	79	1.09	-.1	14	5,434	se.	36	s.	21	5	9	17	6.8	13.3	3.0
Pasco	416	5	33				27.2		50	24	34	3	15	20	26			92	2.06		17	3,520	nw.				5	4	22		~~4.4~~	~~2.3~~
Spokane	1,929	101	110	27.92	30.02	-.06	29.2	-1.3	49	19	35	5	15	24	22	28	27	88	3.88	+1.7	22	2,755	s.	22	sw.	7	3	7	21	8.1	18.4	4.1
Walla Walla	991	57	65	28.92	30.02	-.10	33.1	-2.4	62	19	40	10	14	26	32	30	27	82	2.84	+.8	13	2,818	w.	26	se.	23	2	5	24	8.6	9.6	4.0
Yakima	1,076	58	67	28.84	30.03		24.8	-5.9	45	24	31	-2	15	18	23	24	22	87	3.75	+2.4	17	1,476	se.	15	s.	24	4	9	18	7.6	29.9	16.1
North Pacific Coast Region							41.8	-0.4										84	7.64	+.8										8.6		
North Head	211	11	56	29.61	29.84	-.19	42.2	-1.9	50	19	46	34	14	38	11	41	38	87	11.91	+2.4	28	14,364	se.	72	s.	17	1	3	27	8.9	T.	0.0
Port Angeles	29	8	53		29.83		40.3		55	17	45	28	14	35	17				2.57	-2.2	22	3,205	s.	24	e.	26	0	12	19		.5	0.0
Seattle	125	215	250	29.73	29.86	-.15	41.8	+.1	55	19	46	30	15	38	15	39	36	78	6.54	+.9	26	6,039	se.	37	s.	7	1	8	22	8.2	T.	0.0
Tacoma	194	172	201	29.65	29.86	-.15	41.4	+.8	56	19	46	27	1	36	17				6.88	+.2	23	4,715	s.	37	s.	7	0	8	23	8.5	T.	0.0
Tatoosh Island	86	9	53	29.68	29.78	-.18	42.9	-1.0	51	1	46	35	12	40	9	41	40	89	14.02	+.7	25	13,056	e.	65	sw.	24	3	2	26	8.6	0.0	0.0
Medford	1,329	29	58	28.53	29.97		38.2		64	18	46	16	15	30	32	36	33	83	4.21	+1.1	17	3,959	n.	44	se.	26	2	7	22	8.3	1.6	0.0
Portland, Oreg.	153	68	106	29.75	29.92	-.15	40.2	-1.0	59	18	44	25	1	36	17	37	34	81	8.40	+1.7	24	3,793	se.	20	s.	7	2	2	27	8.8	1.0	0.0
Roseburg	510	75	99	29.38	29.94	-.17	42.3	+.5	62	18	49	27	1	36	32	40	37	83	6.60	+1.3	22	2,540	s.	20	sw.	27	1	5	25	8.8	1.5	0.0
Middle Pacific Coast Region							46.6	-1.8										79	7.73	+3.7										7.1		
Eureka	62	73	89	29.93	30.00	-.12	47.3	-.9	68	17	54	33	12	41	26	44	40	77	9.06	+2.8	20	5,553	se.	42	s.	17	4	8	19	7.3	0.0	0.0
Red Bluff	330	5	58	29.68	30.03	-.10	43.6	-2.5	62	4	51	28	14	37	29	41	37	81	7.95	+3.6	14	4,694	nw.	36	se.	26	7	5	19	7.2	9.0	0.0
Redding	722	20	34				43.4		62	19	49	28	14	38	22			74	9.22		16	5,446	nw.				5	6	20		7.2	0.0
Sacramento	69	106	117	29.98	30.06	-.08	45.2	-1.0	59	4	51	30	12	39	26	43	41	84	6.84	+3.8	16	5,397	se.	31	se.	23	7	8	16	6.6	0.0	0.0
San Francisco	155	208	243	29.87	30.04	-.08	49.4	-1.9	60	4	54	39	14	45	17	46	42	79	9.24	+5.3	20	4,140	se.	29	s.	23	4	9	18	7.4	T.	0.0
San Jose	141	12	110	29.92	30.07		47.4	-2.5	64	18	55	29	16	40	27				5.57	+3.0	17	4,391	se.	29	se.	27	7	5	19	6.9	0.0	0.0
South Pacific Coast Region							51.8	-1.1										71	4.29	+2.3										5.8		
Fresno	327	89	98	29.73	30.10	-.03	46.7	+.5	65	3	54	30	15	39	25	43	40	78	3.36	+1.9	15	3,247	se.	22	nw.	28	5	10	16	7.1	0.0	
Los Angeles	338	159	191	29.71	30.08	+.01	55.0	-1.6	74	17	63	40	15	47	26	46	38	60	5.95	+3.3	8	3,525	ne.	24	e.	14	12	10	9	4.8	0.0	0.0
San Diego	87	62	70	29.97	30.07	.00	53.8	-2.2	69	6	61	39	13	46	25	49	44	74	3.56	+1.7	9	3,409	nw.	30	s.	9	10	10	11	5.4	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.92	30.01		76.8	+.5	83	3	81	68	30	72	13				4.57	-.9	25	10,637	e.	39	e.	14	6	23	2	4.9	0.0	0.0
Panama Canal																																
Balboa Heights	118	6	97	29.73	[1] 29.81	-.01	80.0	0.0	90	16	87	71	26	73	18			[1] 84	4.96	+.6	17	3,960	nw.	20	n.	28	0	20	11	7.2	0.0	0.0
Cristobal	36	6	97	29.80	[1] 29.82	-.01	81.6	+1.7	87	14	86	74	2	78	13	76	74	[1] 80	3.47	-7.4	15	7,806	n.	26	n.	11	6	14	11	6.3	0.0	0.0
Alaska																																
Fairbanks	455	11	44		[2] 29.76		-6.8		32	11	2	-39	18	-15	35			84	1.73		11	1,020	nw.	13	w.	11	11	3	17		24.6	22.4
Juneau	80	11	50	[2] 29.51	[2] 29.60		32.8		43	3	36	23	24	30	12	31	27	77	5.65		17	4,607	s.	26	se.	18	4	8	19	7.8	20.5	4.7
Hawaiian Islands																																
Honolulu	38	86	100	[2] 29.97	[2] 30.01		71.0	-1.4	79	2	76	60	7	66	15	65	62	75	2.08	-1.9	14	6,063	e.	43	e.	20	7	14	10	5.9	0.0	0.0

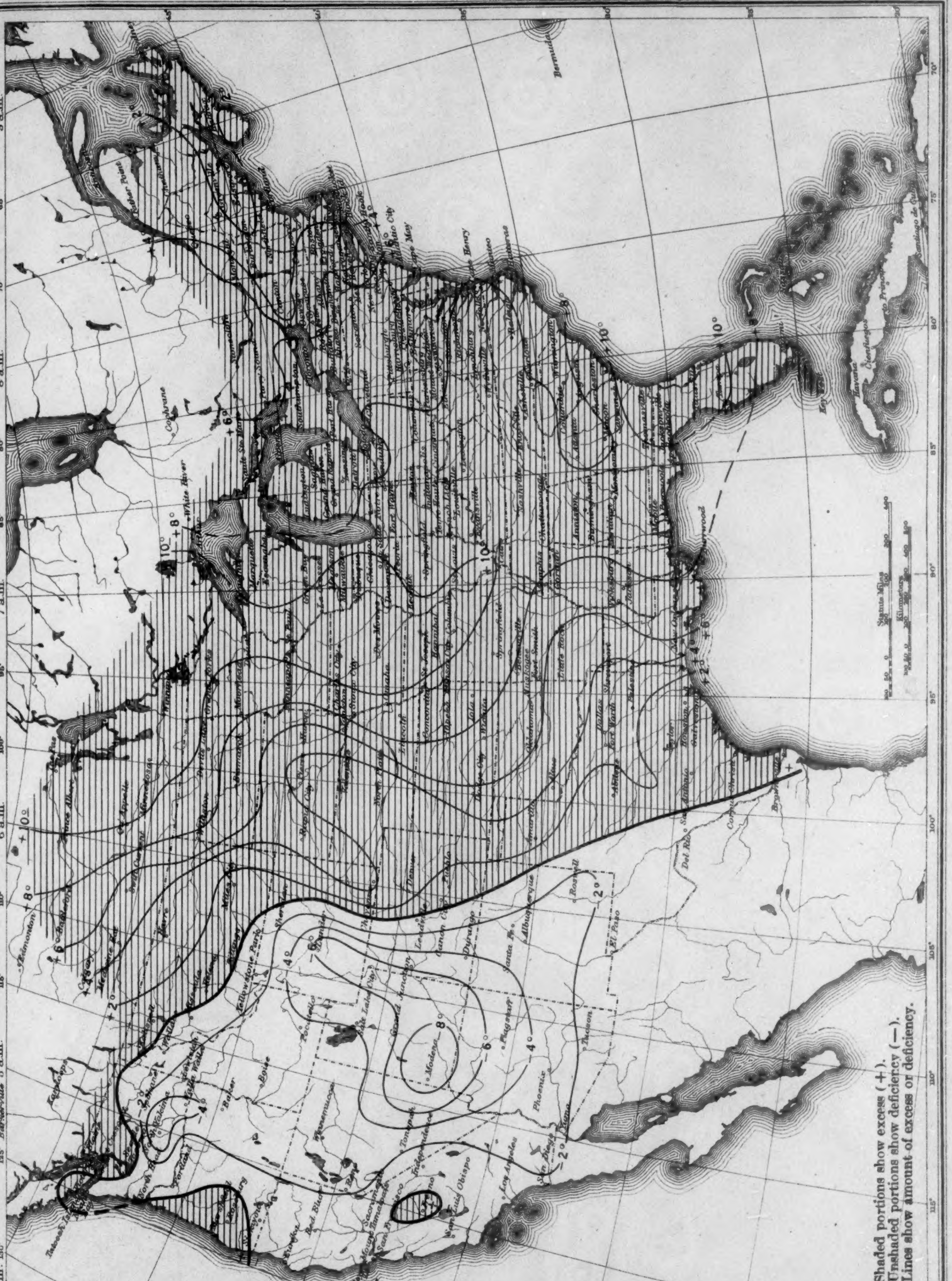
[1] Observations taken bihourly.

[2] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, December, 1931*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max.+mean min.÷2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	*Inches*	*Inches*	*Inches*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*Inches*	*Inches*	*Inches*
Cape Race, N. F.	99				29.6		35.3	23.9	45	6	6.75		20.2
Sydney, C. B. I.	48	29.75	29.80	−0.09	29.4	+1.2	34.8	24.1	45	13	5.51	+0.88	18.5
Halifax, N. S.	88	29.76	29.87	−.09	29.6	+2.0	36.0	23.3	51	8	5.57	+.45	5.0
Yarmouth, N. S.	65	29.79	29.86	−.12	32.8	+2.1	38.9	26.8	51	15	4.51	−.26	3.0
Charlottetown, P. E. I.	38	29.75	29.79	−.15	26.2	+1.9	31.6	20.9	45	4	5.23	+1.57	42.5
Chatham, N. B.	28	29.79	29.83	−.11	20.1	+3.1	28.4	11.8	44	−11	3.00	−.22	24.5
Father Point, Que.	20												
Quebec, Que.	296	29.68	30.02	+.01	19.3	+4.1	25.4	13.2	41	−2	2.71	−.98	21.5
Doucet, Que.	1,236				10.3		22.7	−2.0	37	−30	2.23		21.5
Montreal, Que.	187	29.81	30.03	.00	24.7	+6.4	31.8	17.5	46	−1	3.36	−.29	20.0
Ottawa, Ont.	236	29.80	30.09	+.07	23.9	+6.9	31.5	16.3	48	−2	2.51	−.40	12.4
Kingston, Ont.	285	20.76	30.09	+.05	30.1	+6.4	37.3	22.9	48	4	2.53	−.71	3.0
Toronto, Ont.	379	29.67	30.10	+.05	33.3	+6.3	38.8	27.8	51	10	3.00	+.00	6.3
Cochrane, Ont.	930				14.7		23.5	5.9	38	−18	1.47		9.1
White River, Ont.	1,244	28.68	30.04	+.07	16.5	+6.8	27.0	6.0	40	−20	1.06	−.65	10.6
London, Ont.	808				32.9		38.8	27.0	53	17	2.10		3.4
Southampton, Ont.	656	29.35	30.08	+.07	31.3	+4.6	37.1	25.5	46	9	2.97	−1.01	12.2
Parry Sound, Ont.	688	29.37	20.08	+.08	26.0	+4.8	32.9	19.1	44	−2	2.90	−1.58	15.7
Port Arthur, Ont.	644	29.33	30.06	+.07	25.5	+12.3	32.0	19.1	43	0	.96	+.09	4.7
Winnipeg, Man.	760												
Minnedosa, Man.	1,690	28.12	30.01	−.01	16.5	+10.8	24.7	8.4	39	−19	.05	−.57	.5
Le Pas, Man.	860				10.9		20.8	1.0	37	−23	.54		5.4
Qu'Appelle, Sask.	2,115	27.60	29.92	−.08	19.0	+11.6	26.5	11.5	40	−16	.48	−.04	.4
Moose Jaw, Sask.	1,759				22.3		31.8	12.8	45	−9	.55		2.2
Swift Current, Sask.	2,392	27.26	29.88	−.11	21.7	+5.7	29.2	14.2	44	−8	1.30	+.52	10.9
Medicine Hat, Alb.	2,365												
Calgary, Alb.	3,428												
Banff, Alb.	4,521												
Prince Albert, Sask.	1,450	28.32	29.97	−.04	13.5	+10.7	21.9	5.1	40	−20	1.34	+.60	13.4
Battleford, Sask.	1,592	28.13	29.95	−.04	12.7	+7.3	22.7	2.8	43	−19	.85	+.53	8.5
Edmonton, Alb.	2,150												
Kamloops, B. C.	1,262												
Victoria, B. C.	230	29.57	29.83	−.14	41.8	+0.6	44.9	38.7	53	32	2.62	−5.36	.6
Barkerville, B. C.	4,180												
Estevan Point, B. C.	20												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151	30.04	30.20	+.08	65.9	+1.2	72.4	59.3	77	50	2.11	−2.38	

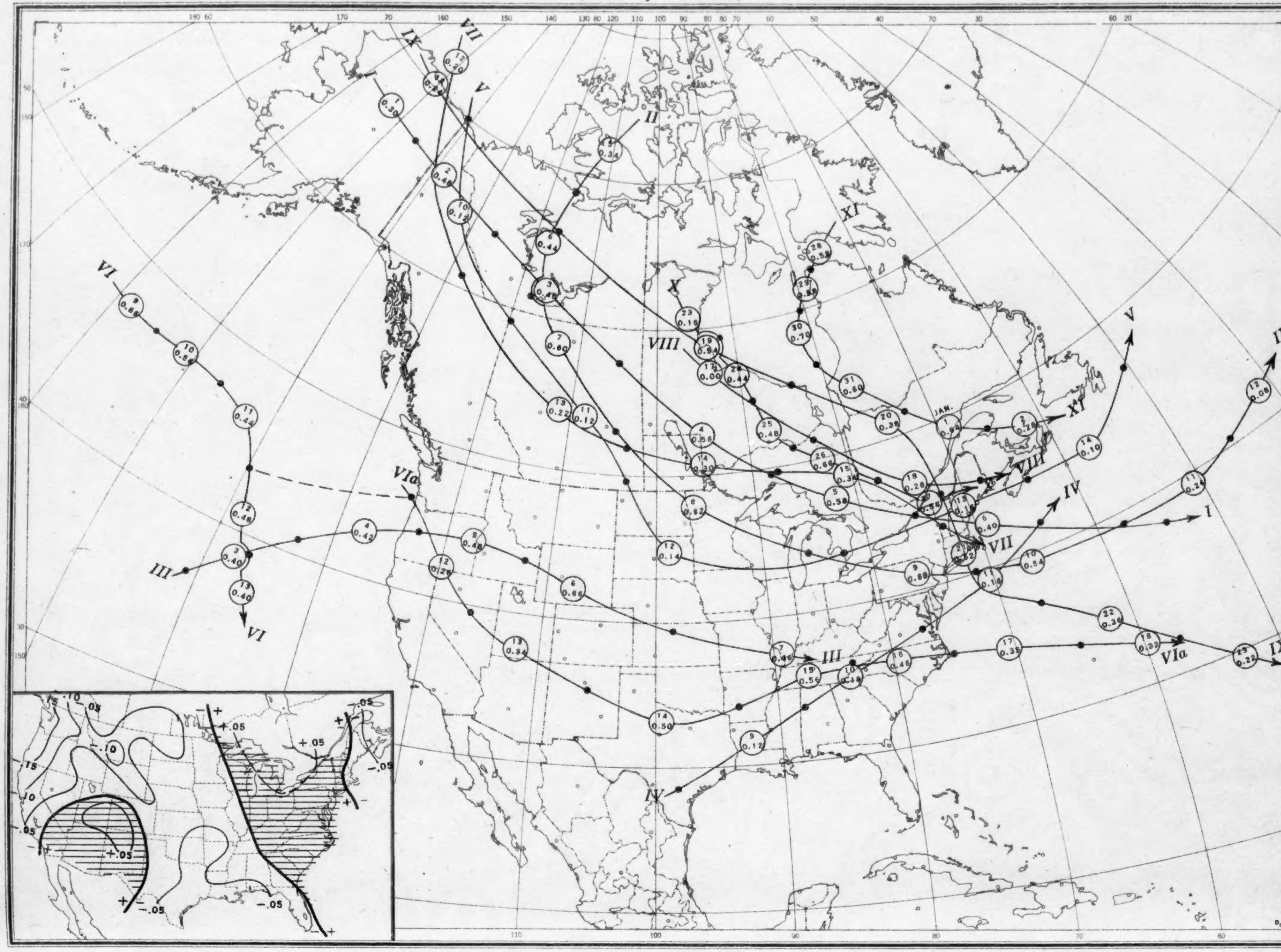
Chart I. Departure (°F.) of the Mean Temperature from the Normal, December, 1931



Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

Chart II. Tracks of Centers of Anticyclones, December, 1931. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by G. E. Dunn)



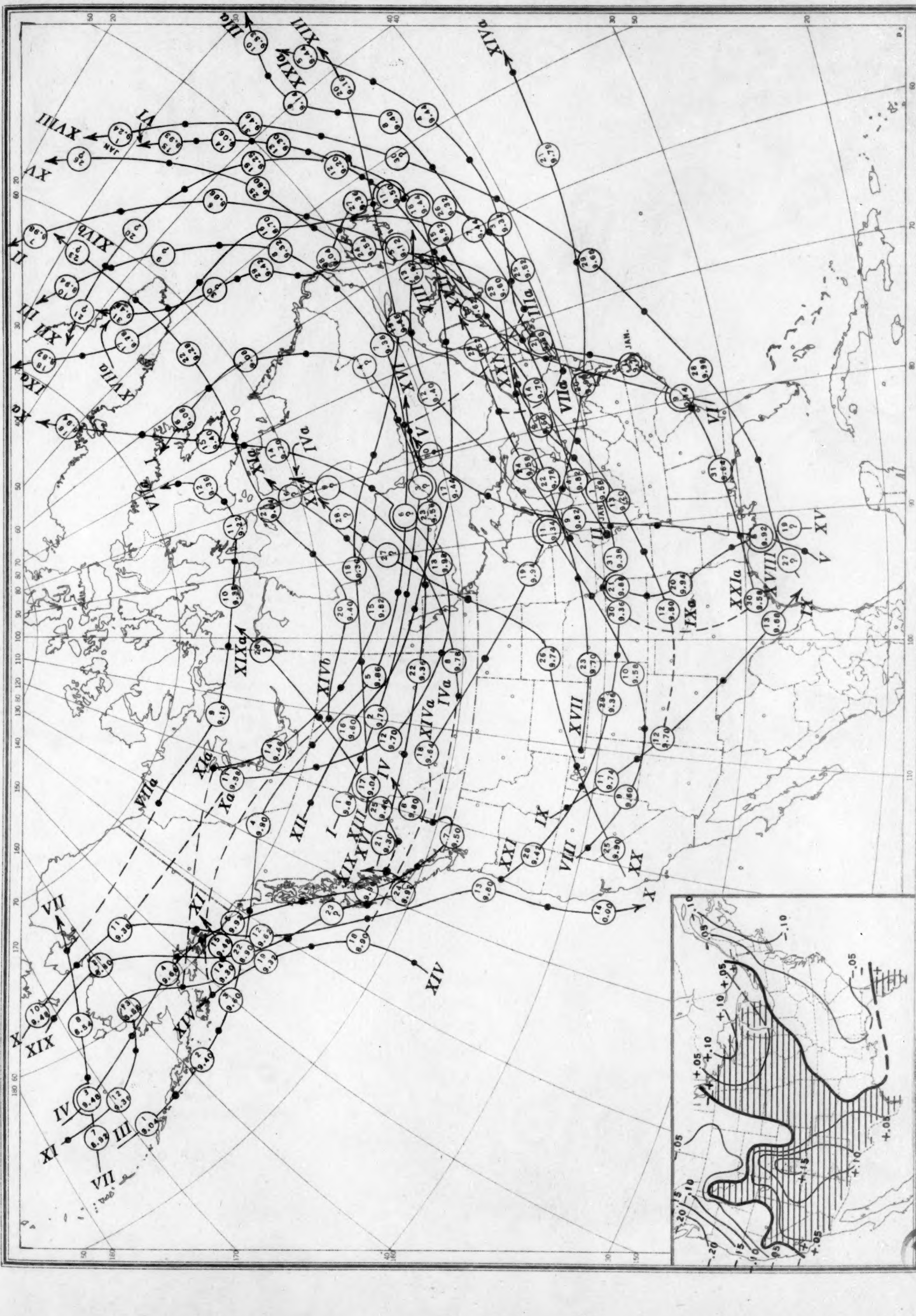
Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, December, 1931. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by G. E. Dunn)

Chart III. Tracks of Centers of Cyclones, December, 1931. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by G. E. Dunn)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, December, 1931

Chart V. Total Precipitation, Inches, December, 1931. (Inset) Departure of Precipitation from Normal

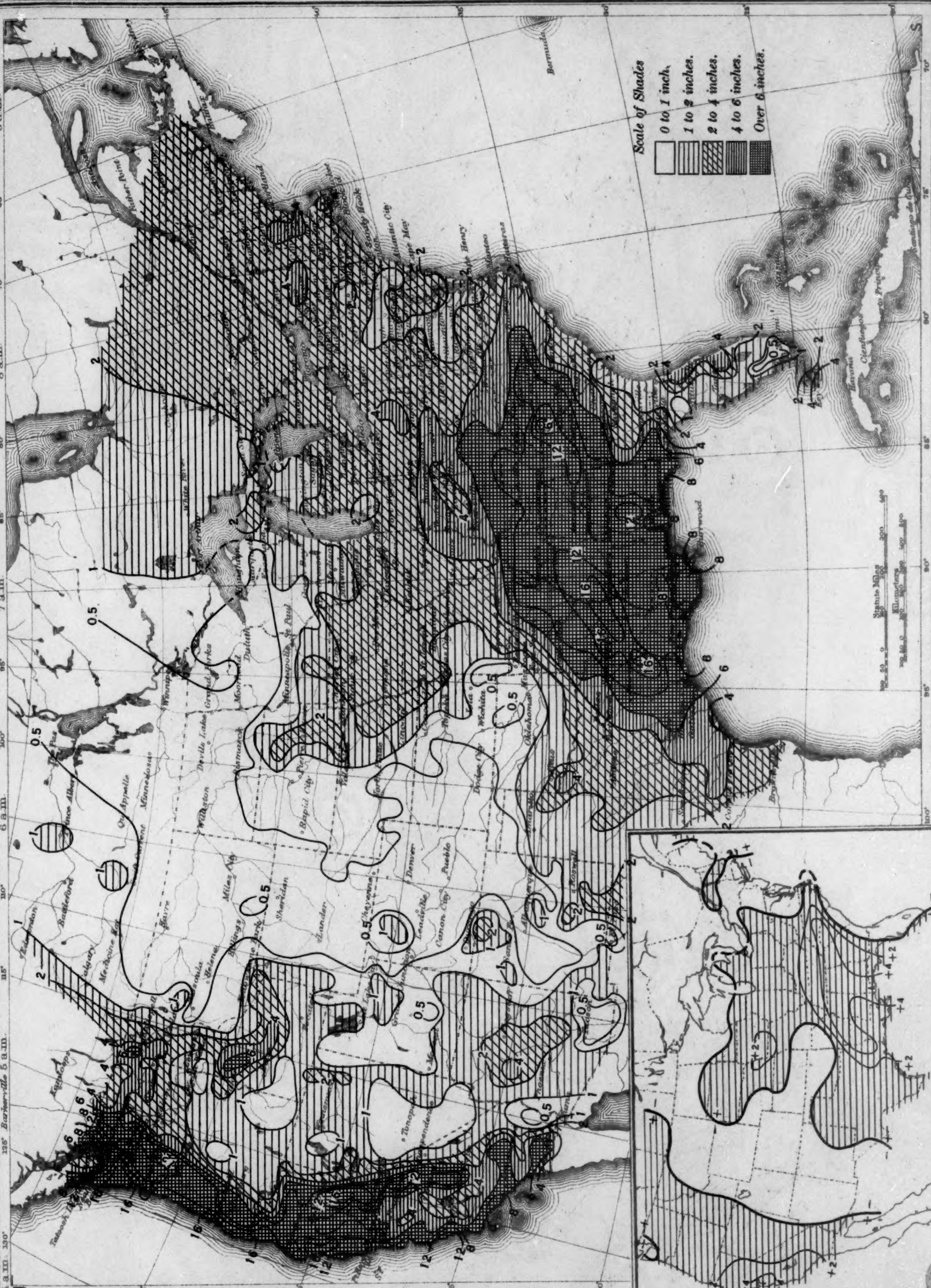


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, December, 1931

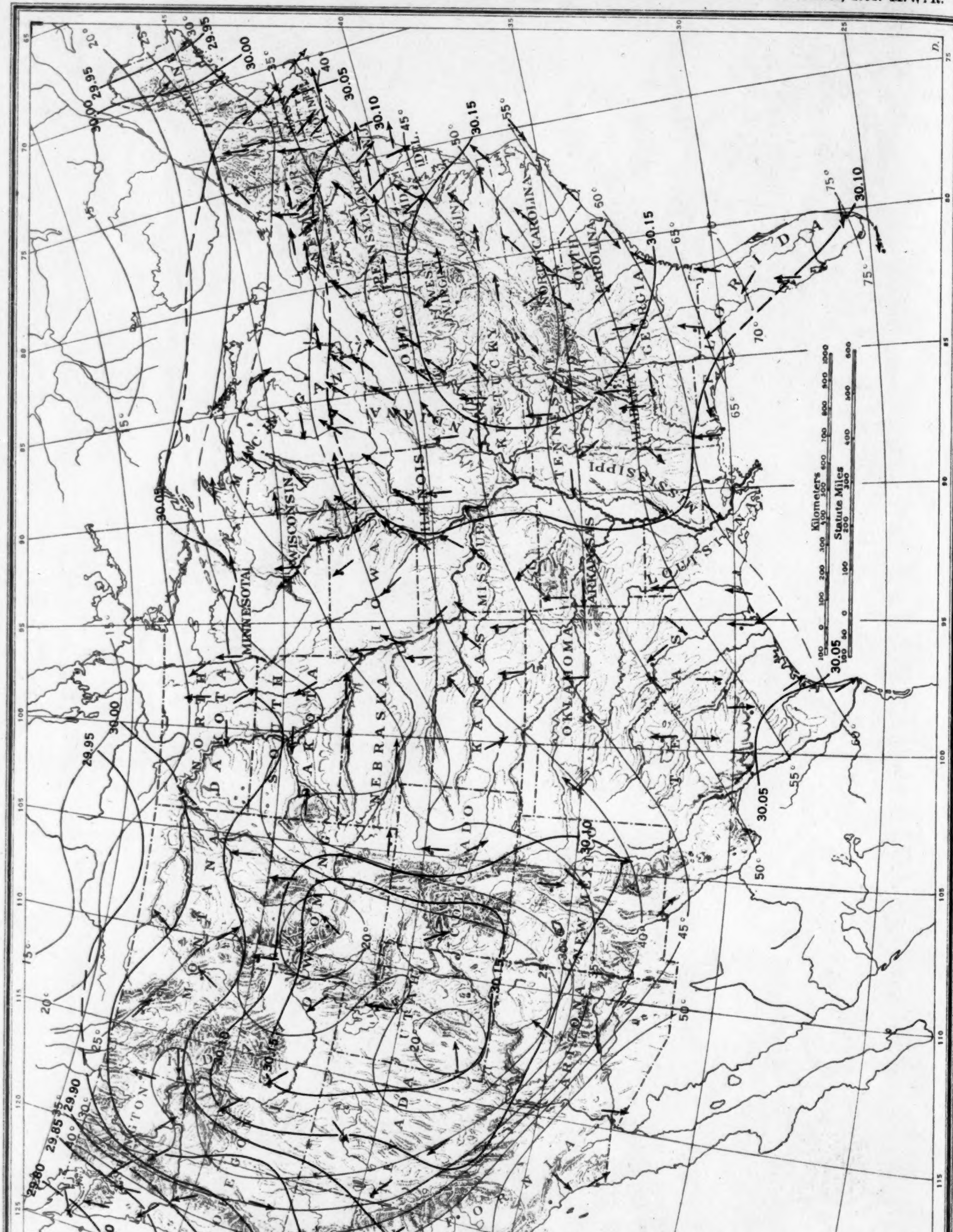


Chart VII. Total Snowfall, Inches, December, 1931. (Inset) Depth of Snow on Ground at end of Month

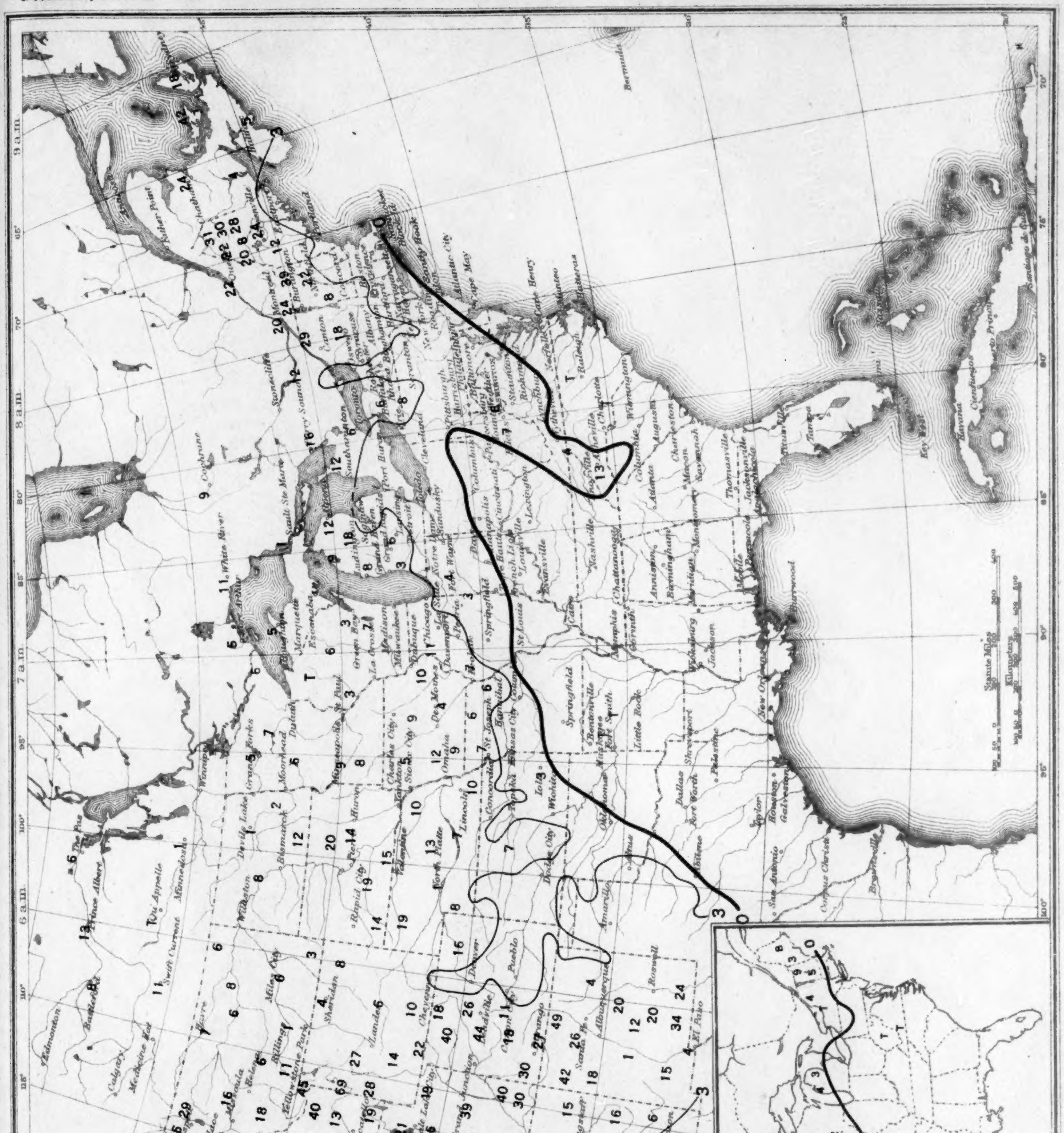


Chart VIII. Weather Map of North Atlantic Ocean, December 6, 1931
(Plotted from the Weather Bureau Northern Hemisphere Chart)

Chart VIII. Weather Map of North Atlantic Ocean, December 6, 1931
(Plotted from the Weather Bureau Northern Hemisphere Chart)

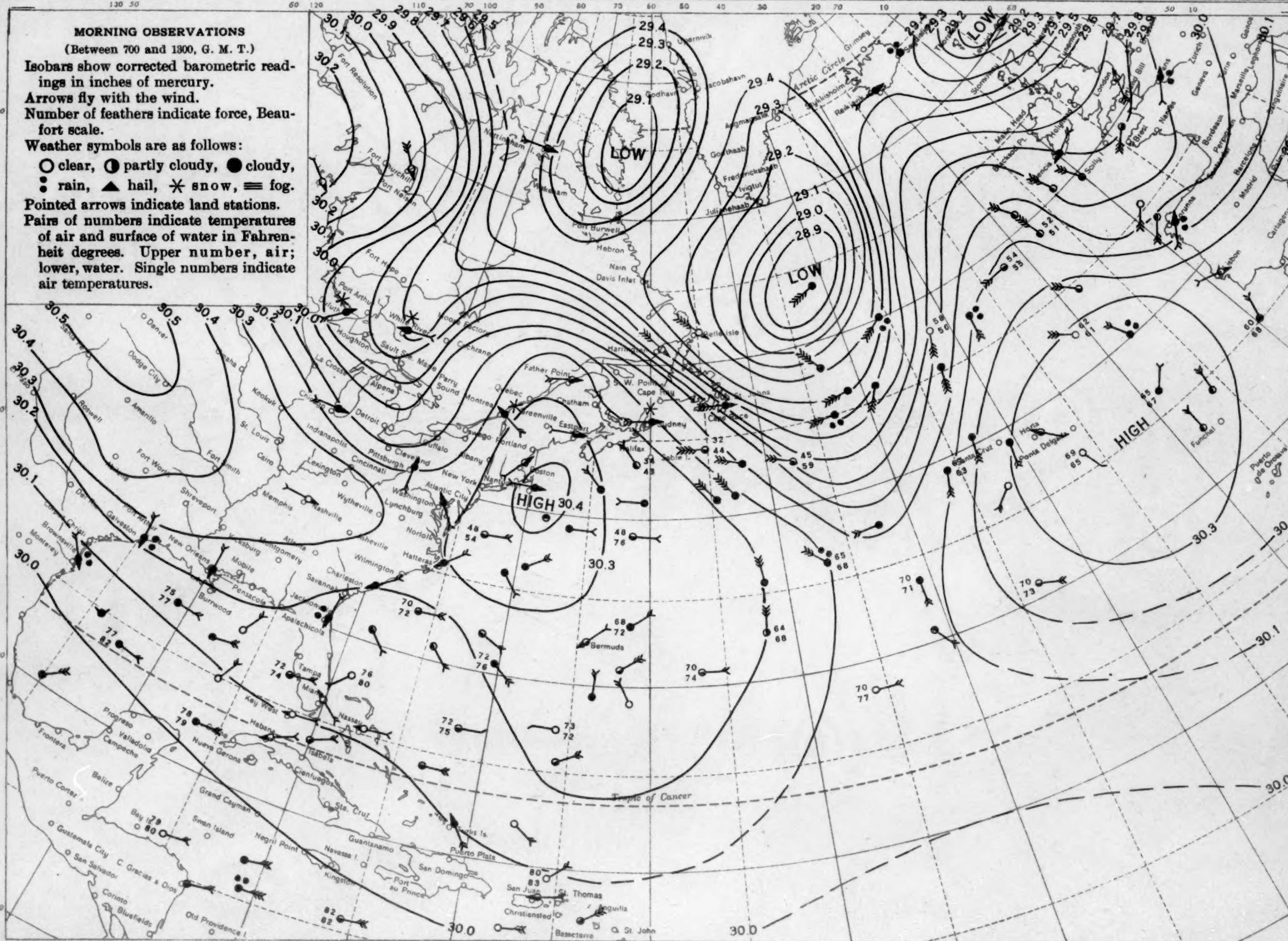


Chart IX. Weather Map of North Atlantic Ocean, December 16, 1931
(Plotted from the Weather Bureau Northern Hemisphere Chart)

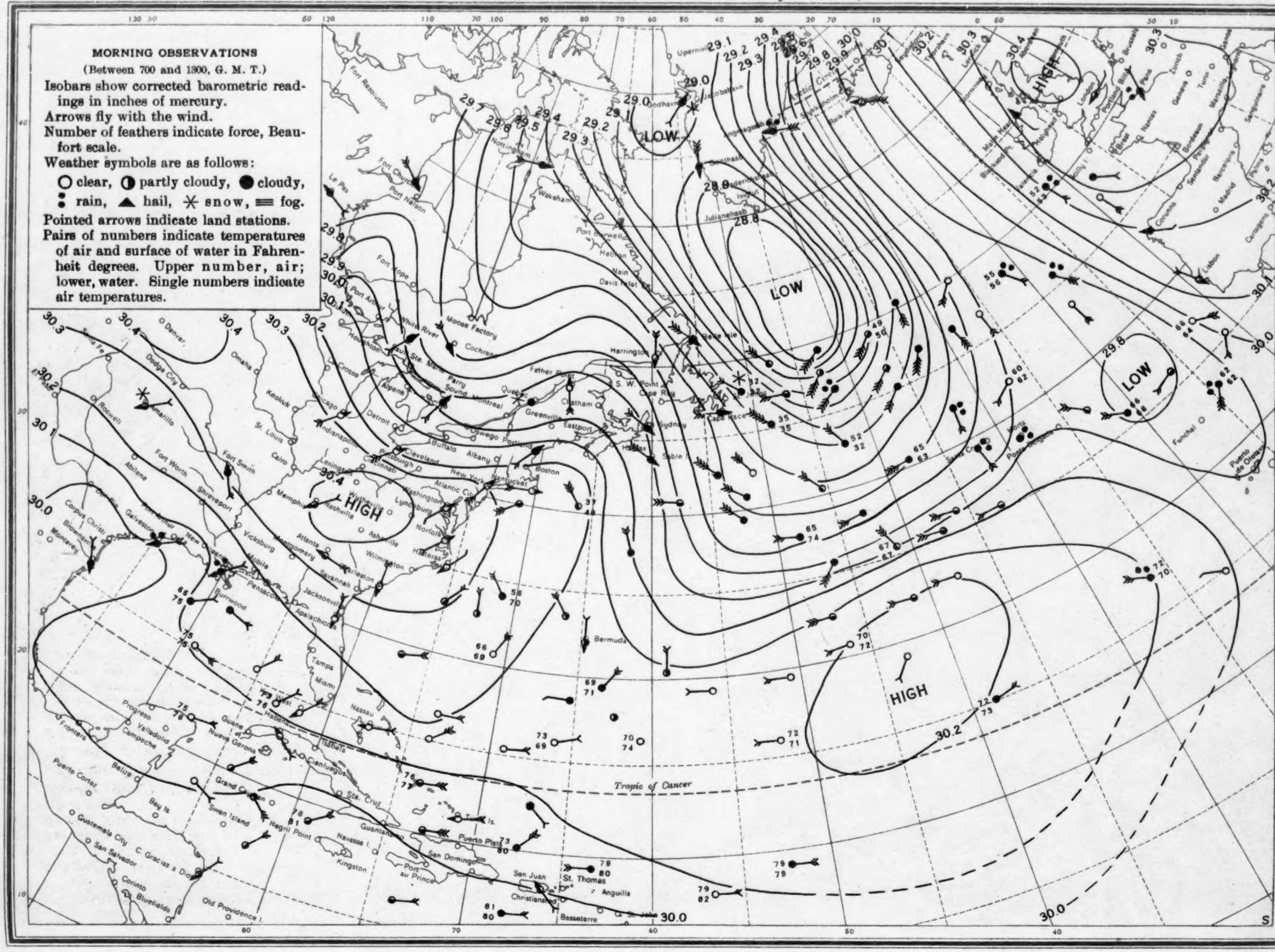


Chart X. Weather Map of North Atlantic Ocean, December 18, 1931
(Plotted from the Weather Bureau Northern Hemisphere Chart)

Chart X. Weather Map of North Atlantic Ocean, December 18, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)

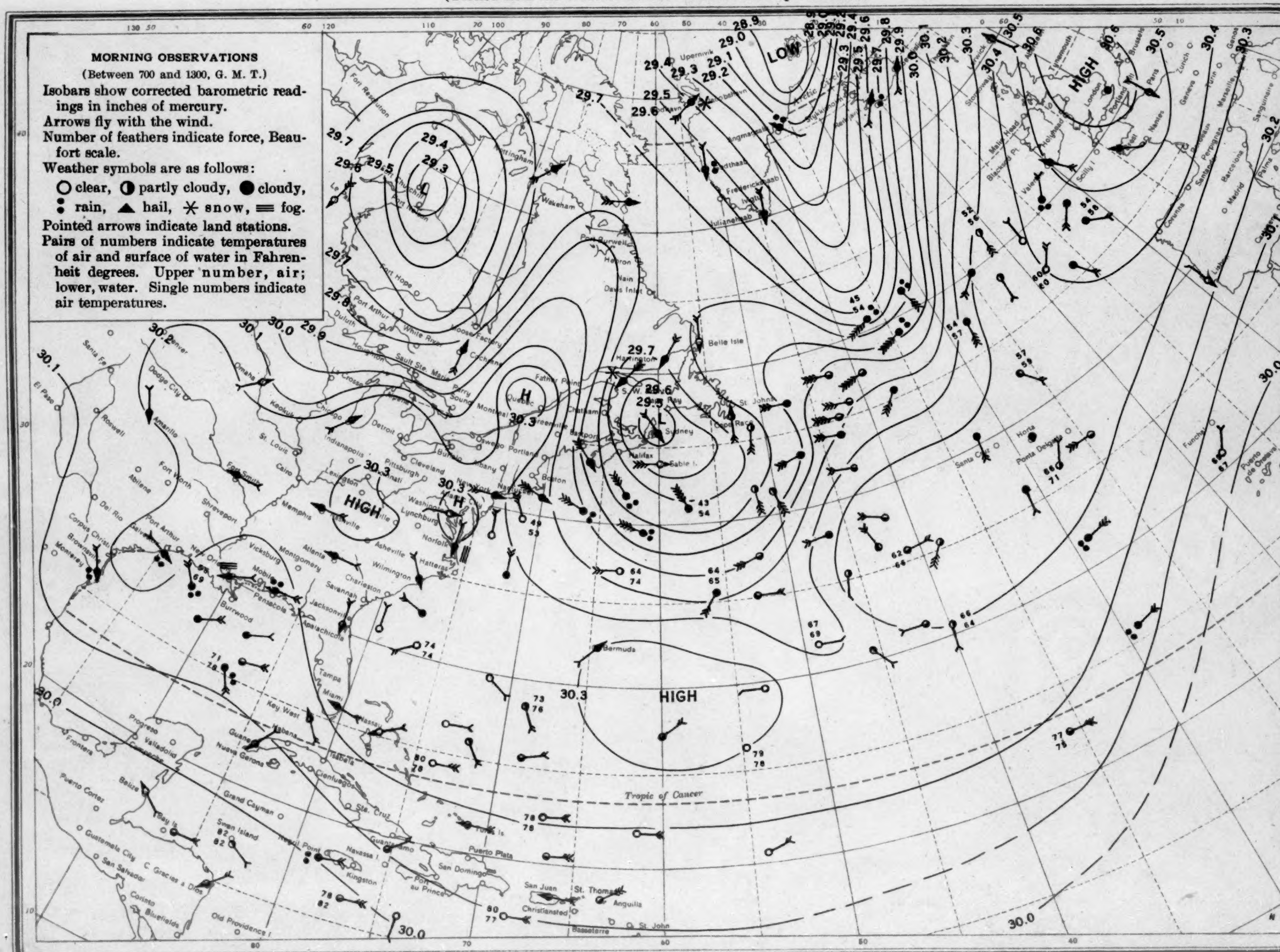
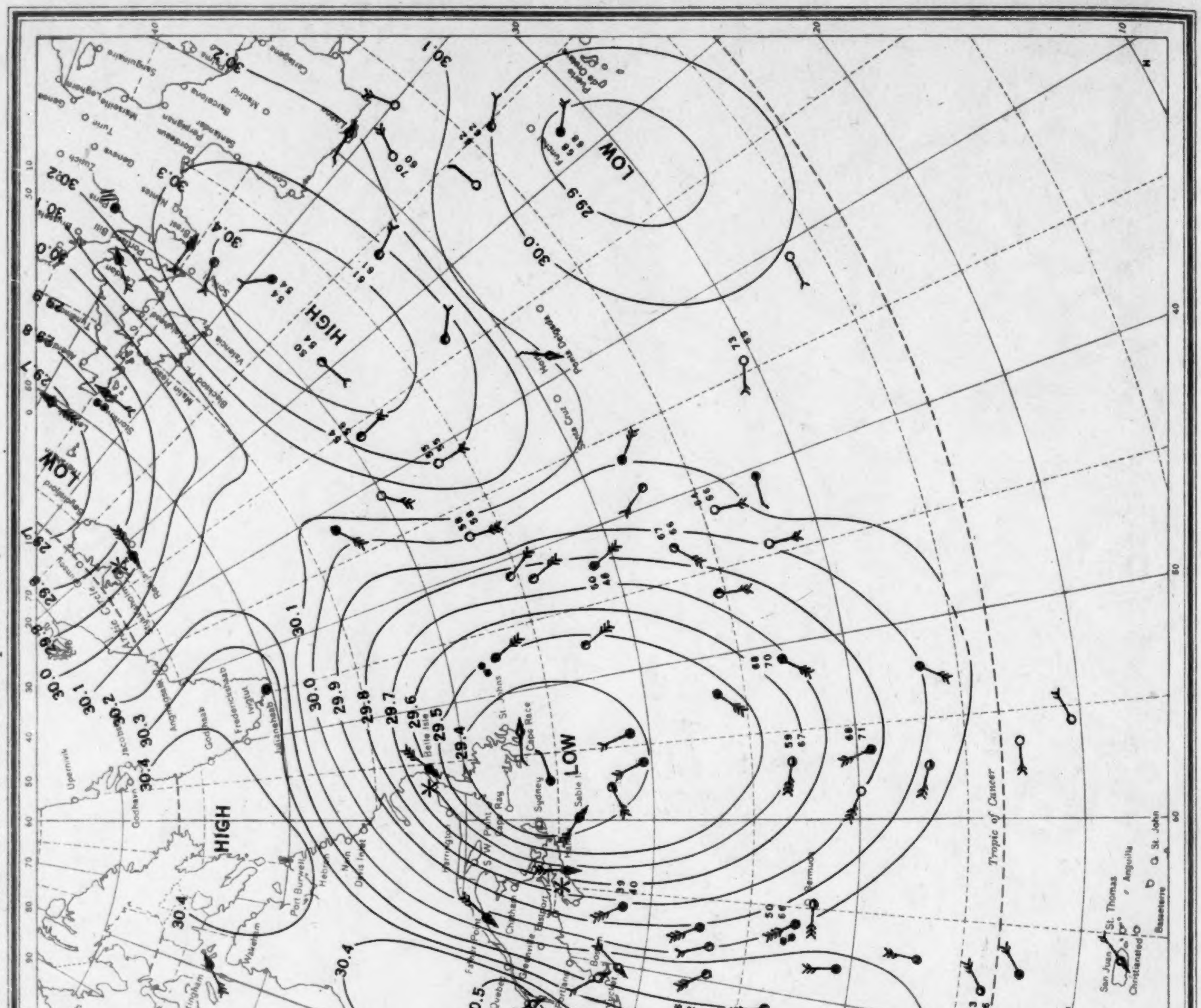


Chart XI. Weather Map of North Atlantic Ocean, December 27, 1931
(Plotted from the Weather Bureau Northern Hemisphere Chart)



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